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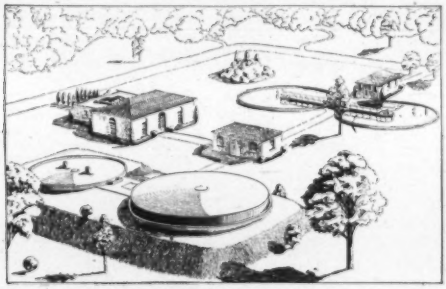

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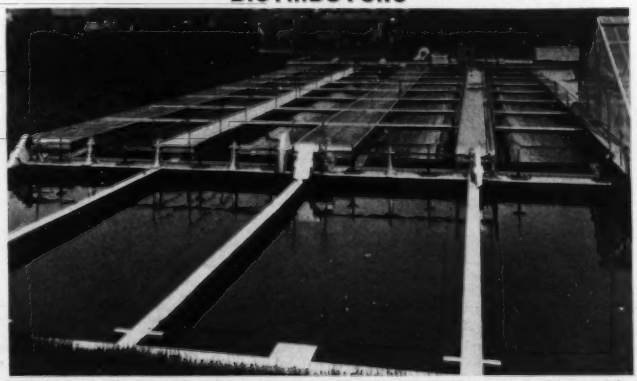

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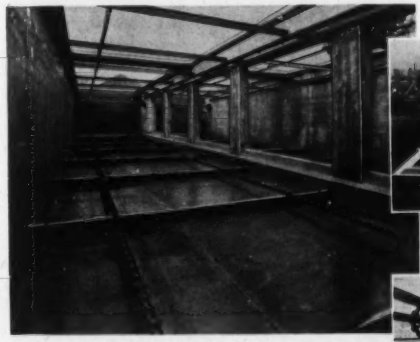

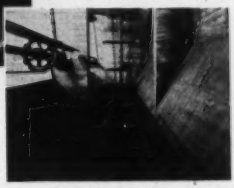

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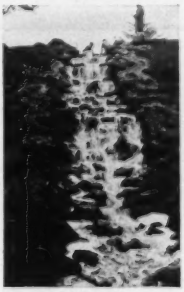

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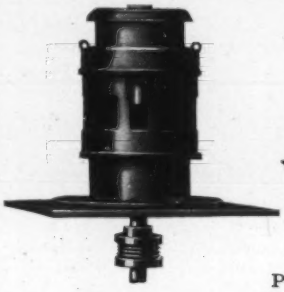

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Sewage Research

RESEARCH IN SEWAGE CHEMISTRY, SEWAGE TREATMENT AND STREAM POLLUTION

A CRITICAL REVIEW OF THE LITERATURE OF 1933

By Wellington Donaldson, Linn H. Enslow, Samuel A. Greeley, W. S. Mahlie, Willem Rudolfs, Abel Wolman, and Earle B. Phelps, *Chairman*

Committee on Research, Federation of Sewage Works Associations

Chemistry and Biology

Studies dealing with methods of determining sewage, sludge and effluent characteristics are progressing slowly. The study of organic and inorganic colloidal substances present in sewage, their behavior and changes with different methods of treatment, is very much in its infancy. Scientific information regarding the quantities and behavior of colloids in sewage is of particular importance in the activated sludge process and other oxidation devices, in the settling, decomposition and precipitation of organic matter in sewage, and last but not least, in the dewatering of sludges.

Determinations of colloidal matter in sewage vary greatly in accordance with the method used. Among these methods are those used by Richter, involving coagulation of the colloids with $FeCl_3$ and NH_4OH, treating the $Fe(OH)_3$ with H_2SO_4 and determining the colloids by filtering through a Gooch crucible and weighing; Rohland and Meysohn, adsorption of dyes by colloids and colorimetric determinations of the concentration of the dye before and after absorption; Marc and Sack, adsorption of colloids with $BaSO_4$ powder and determining the refraction of the water before and after treatment; Bach, adsorption with $BaSO_4$ and determining the oxygen consumed with $KMnO_4$ before and after; Nue, filtration of colloids through crude rubber and collodion as an ultra-filter and determination of total solids before and after ultrafiltration; and several others. All procedures give different results, however, and are for the most part tedious. Schmiedt [1] has recently proposed a method consisting of precipitation with $FeCl_3$ (1:19) at a pH of 4.0, taking care that no surplus $FeCl_3$ is added by trials with KCNS solution at pH 4.0, which is considered to give the lowest oxidation value, and oxygen consumed determinations before and after filtration in accordance with the regular $KMnO_4$ method. The difference be-

tween the two oxygen consumed values is the oxygen consumed (chemically) by the organic colloids.

Lumb,[2] discussing the mechanism of the action of activated sludge, states that the isoelectric point of sewage is estimated to be about pH 6.5. Since sewage usually has a pH value between 7.0 and 8.0 the colloids are considered to carry a slightly negative charge. The bacteria are always negatively charged, and during periods of active growth the potential difference between them and the surrounding liquid is considerably greater, *e.g.* the bacteria have a strongly negative charge. Activated sludge (sewage pH 7.0 to 8.0) is also strongly negative and the sewage colloids are weakly negative. Under these conditions the sewage colloids and the activated sludge will undergo co-precipitation; in effect the sewage colloids will be flocculated on the activated sludge floc.

The practical application suggested is to acidify the sewage with a cheap acid to about pH 6.5 in order that greatest clarification may be obtained.

A method of classification of dispersed materials in sewage has been undertaken by the British Water Pollution Research Board [3] by means of filters, ultra-filters, sedimentation, centrifuging and chemical means. The dispersed matter may be divided in 3 classes according to particle sizes by centrifuging at 2500 r.p.m. The coarser material contains one-half to three-fourths of the organic carbon, while the finer particles not separated at 2500 r.p.m. contain nitrogen and are possibly of protein character.

The biochemical, biophysical and physical principles underlying the treatment of sewage have been discussed in several papers. Prof. Adeney,[4] who has been identified with sewage research for many years, contributed a paper summarizing somewhat critically our present knowledge and giving the relationship of strength of organic and ammoniacal impurities in crude sewage of average strength, expressed in parts per million by weight of oxygen consumed during self-purification. His classification is as follows:

	Parts per Million
Coarse solids removable by sedimentation	200
Fine suspended and colloidal removable by activated-sludge process	450
Organic and ammonia in solution	
a. Organic	170
b. Ammoniacal	180

These figures are of interest in that they indicate that 79 per cent of the organic impurities (820 p.p.m.) are in the form of solid organic matter.

A laboratory study made by Emma Hamburg-Eisenberg,[5] dealing with the value of protozoa in activated sludge, leads her to conclude that the protozoa are found almost exclusively on the surface of the floc.

Protozoölogical estimations seemed to show that a special fauna produced a specific degree of purification. The conclusion was reached that the protozoön fauna, from both a qualitative and a quantitative standpoint, is a very good index of the purifying power of activated sludge. The coating of slime adhering to the walls was investigated and found to be very important. By decreased aeration the load on the tank could be doubled when a good growth of slime was present.

Contributions to our knowledge of sewage fungi are infrequent. Butcher [6] described five organisms more or less commonly found. The organisms are found wherever a sufficient quantity of certain forms of organic matter is present; they develop without regard to the oxygen content of the water and are distributed according to the quantities of organic matter present. Low temperatures may increase distribution by retarding decomposition.

Two studies were reported simultaneously on the effect of dilution on bacterial numbers in sewage. Studies on polluted river waters by Hoskins and Butterfield [7] showed that bacteria increased by dilution, followed by a decrease. The same was found by Heukelekian [8] when sewage was diluted in the laboratory. (See pages 195 and 197 for further discussion.)

Filters.—Control of the filter fly is still under study. Investigations of the use of chemicals, heat and flooding recur periodically. Scouller and Goldthorpe [9] tried creosote oil, orthodichlorbenzene, soda ash and grease, in the form of emulsions, on a large scale with a measure of success, although the eggs, larvae or pupae were not killed. The application of none of these materials either singly or combined is new, but in Scouller's work applications were made during two seasons on a large scale, with a cost during the second season of $206 per acre.

Nitrification in trickling filters continues to interest investigators. Barritt [10] concluded that ammonia oxidation reaches its optimum at pH 6.7 to 8.0 and is retarded at pH 5.5. Free CO_2 retards. Bach [11] concludes that 0.4 per cent CO_2 in the air is toxic and that the concentration should be kept below 0.2 per cent. Blunk [12] has assumed on the basis of studies by Bach that the CO_2 concentration in filters is so great that nitrification is retarded and consequently he has applied air artificially to sweep out the CO_2. His studies showed that the time of passage of sewage through the filter varies from 1 to 5 hours, instead of a few minutes as is frequently supposed. For that reason he concludes that continuous operation would be better than intermittent.

The biological decomposition of gas house waste on filters was investigated by Hoppold and Key.[13] Fowler, Ardern and Lockett in 1910 isolated a bacterium capable of oxidizing phenol, while Wlassowa in 1930 claimed that phenol decomposition in sewage is purely a chemical

phenomenon. The two authors have tried to settle the question and came to the conclusion that only one isolated Gram negative vibrio was capable of splitting phenol. Gas house waste containing relatively high concentrations of phenol (concentrations not given) was detrimental to all other sewage bacteria so that biological stabilization was ineffective.

A study of the destruction of carbohydrates and organic acids by bacteria from a trickling filter was reported by Levine and Watkins.[14] About 90 bacterial strains were isolated on a synthetic lactic acid medium. These included 18 species and 9 genera. Acids were produced in the upper layers of the filter from sugars, starches and other carbohydrates, whereas they were destroyed in the lower layers. The pH of the effluent was found to be a convenient and rapid index of functional activity.

The effect of type and size of sprinkling filter media on the purification and stabilization of sewage was investigated by Rudolfs, Setter and Heukelekian.[15] It appeared that the per cent reductions of B.O.D., ammonia and *B. coli* and the rate of nitrification varied with the temperature of the sewage, while B.O.D. reduction and nitrification were also influenced by the concentration of suspended solids. Saturation with dissolved oxygen was not affected by temperature; protozoa variations were related with *B. coli* reductions. Slag retained more solids than stone or gravel. The results of studies of size of media showed that stone, gravel or slag filters were about equal in general purification, whether coarse or fine media, but the differences between fine and coarse material were quite marked. With increasing B.O.D. loads poorer effluents were produced, although the percentage reduction was greater. A large portion of the ammonia could not be accounted for. It would be valuable if studies of this nature would be duplicated elsewhere under different climatic conditions and different sewage characteristics.

Sludge.—Discussion of heat production during digestion continues to be of interest. Keefer and Kratz [16] concluded from laboratory studies that digestion is exothermic during the early stages and endothermic in the later stages. During the entire decomposition process more heat is absorbed than given off. In the discussion between Buswell and his co-workers [17] and Fair and Moore [18] concerning thermodynamic considerations, the former concluded that absorption of energy (endothermic) during bacteriological degradation of sewage solids is contrary to the mass of data collected by previous workers in the field using pure compounds.

Studies of the effect of temperature on digestion have dealt particularly with the zone between so-called optimum conditions for mesophilic and thermophilic digestion. Keefer and Kratz [19] found that with small

batches the sludge kept at 37° C. digested slightly more rapidly than that at 28° C., while Heukelekian [20] concludes from experiments where the sludge produced was re-used that the ultimate digestion time does not vary materially in the range of temperature between 28° and 42° C. Variations of temperature in different sections of a digester have again been called to attention by Taylor,[21] who heated the top sludge to produce better results. That sludge has a relatively low coefficient of heat transmission from a heating coil was shown by Queer.[22] This is assumed to be due to the high viscosity of sludge. Heat transfer was highest in the region of active digestion.

Results on semi-plant scale operation of thermophilic digestion of fine screenings (349 days at 130° F.) as compared with mesophilic digestion (267 days at 85° F.) given by Heisig [23] show that the daily charges handled were about the same, while gas production from the thermophilic digestors was considerably higher. Other results showed that the daily charges to the thermophilic tanks could be as much as 70 per cent greater than the mesophilic with equally good results. The gases contained an average of 53.8 per cent methane. Additions of trypsin to the screenings and digestion at 104° F. showed that the same amounts of materials could be handled as in the tank kept at the same temperature without trypsin additions, but that gas production was reduced.

A few studies have been made on the ripeness of sludge. Althausen and Buswell [24] conclude that the rate at which water can be expressed from sludge varies with the ripeness, but that the amount of water reabsorbed by dried press cake was independent of the ripeness. Results on so-called "two stage" digestion, which in reality is short-time digestion in one tank and after-digestion in another, have been brought forward as something new, although the same procedure has been followed for a great many years at Birmingham, England, and at the Essen-Rellinghausen plant in the Ruhr district. At Peoria, Ill.,[25] it was found that 40 per cent of the volatile matter will digest at 90° C. in a ten-day period and the remainder of the digestible material at a lower rate at lower temperatures.

Activated Sludge.—Indices used by Ridenour [26] to predict bulking of activated sludge were: increase in volatile content of suspended solids, increase in dissolved oxygen, rapid increase in B.O.D. and increase in filamentous character of the sludge. Scouller and Spencer,[27] while investigating the effect of iron on activated sludge, added gradually from 10 to 100 p.p.m. as ferrous sulphate. The iron did not interfere with clarification, but inhibited nitrification. With more than 100 p.p.m. iron purification was definitely decreased, but the sludge gradually recovered its activity. Eldridge [28] reports that dairy waste tested in an activated sludge plant, aerated for 5.5 hrs., began to bulk; that a scum of fat was

present on the final tank; lactose was present in the aeration tanks and effluent; and a drop of pH from 7.0 in the morning to 6.7 in the afternoon was recorded. The lower pH would be nearer the optimum for coagulation as expressed by Baly for domestic sewage.

Methods of Analysis.—During the determination of moisture in sludge at 100° to 105° C. volatile matter is lost. Bach [29] has used a method of moisture determination based upon that used in coal analysis. The sludge is distilled with xylol vapor and the water collected. Checking of the method in the laboratory of the New Jersey Experiment Station has shown that it is satisfactory for rather concentrated sludges, but very inaccurate when activated sludge or similar thin sludges are used.

Although a committee report has fairly well standardized the procedure of B.O.D. determinations, not all difficulties have been solved and the necessity of incubation for a number of days delays results. Eldridge [30] has pointed out that dilutions of a sterile material and the quantities of such material affect the values obtained. Thompson [31] criticized the British Royal Commission test described in the Ministry of Health Methods. A modification of Miller's method of determining dissolved oxygen was described in detail and Thompson concluded that it was simpler and more accurate than the R. C. test. To avoid errors inherent in the dilution method of estimating B.O.D. it was proposed to saturate the undiluted sample with oxygen instead of air and incubate for 24 to 48 hours. The main difference between Thompson's proposal and the Sierp method is that in the former oxygen is bubbled through the sewage, thereby bringing it in solution, while in Sierp's method the sewage is incubated in the presence of gaseous oxygen. The question remains whether such a method evaluates the load placed upon a stream better than the dilution method, since in a stream some degree of dilution takes place.

A Committee of the New England Sewage Works Association [32] has published a valuable report on sewage sampling procedure. Methods of determining the operating characteristics of the activated-sludge process are of particular interest. It is well known that the sludge index may be valuable when applied for comparative purposes at a single plant, but laboratory results published by Voelker [33] indicate that there are critical points for the concentration of suspended solids in the aeration tank for clarification as well as for stabilization. These two optimum points are not necessarily the same and will undoubtedly vary with the chemical and biological characteristics of the floc.

Chemical Precipitation.—In spite of the widespread interest in chemical precipitation, no results of laboratory research were published during 1933. A number of chemical precipitation schemes have been proposed and utilized, but there has been a dearth of fundamental research dealing

with questions such as the reactions involved, effect of interfering substances, effects of dispersion, flocculation and coagulation of the colloidal and soluble materials. The need for more effective precipitants than those utilized at present is apparent. Results with small dosages of ferric chloride at Grand Rapids [34] produced a small increase in the removal of suspended solids, reduction of B.O.D. and chlorine demand. Similar results are reported from several places.

Work on the chemical precipitation of trade wastes is being conducted at several places in this country and abroad. Most of the work is along well-known lines, with the use of lime, alum, calcium chloride, ferric chloride, copperas, sulphuric acid, etc. Textile wastes liquors have been and still are being studied. Some of the latest work done in North Carolina [35] is of interest, although the work is not concluded. The investigators came to the conclusions that each type of textile waste requires specific chemicals or mixtures of chemicals for satisfactory coagulation. Several studies have been reported on treatment of sugar wastes either by biological or chemical methods.

Treatment of gas house liquors has been studied by a number of investigators. The use of copper sulphate as a precipitant, although somewhat expensive, produced fairly efficient precipitation.[36]

Sludge Digestion

The year 1933 in sludge digestion was characterized by construction of relatively few new plants, by an increasing influence of operating experience on design, by a vastly increased interest in the utilization of sludge gas, and by investigations into the mechanical dewatering of sludge.

Gas engines for utilization of sludge gas have been installed at the sewage treatment works at Springfield, Illinois, and Newark, N. Y., and at one or two places in Germany. Walraven [37] reported for nine months in 1933 the use of power from sludge gas, and warned regarding variations in the quality and quantity of sludge gas, the pressure at which it is generated, and the content of hydrogen sulphide. Definite steps have been taken for the installation of gas engines at the Peoria, Illinois, sewage treatment plant. Haseltine [38] stated that the composition, quantity and heat value of sludge gas may vary considerably, but the variations in heat value become almost negligible in the air-gas mixture used in the engine. Variations in the methane content require adjustment of the air-gas mixture. Not more than 0.1 per cent of hydrogen sulphide should be present in gas used for power. Vokes [39] discussed the recovery of heat from exhaust gases of gas engines at the Saltley and Yardley works of the Birmingham, Tame and Rea District.

New construction in this country in separate sludge digestion is limited to very small installations. Prüss and Blunk [40] described a plant at Soest, Westphalia, including both trickling filters and activated sludge, for a population of 25,000. Fresh sludge, collected in a storage tank holding two days' supply, is pumped to a digestion tank heated by hot water coils and equipped with screw pumps for vertical circulation. Gas is collected and used for all power requirements, and digested sludge is used as fertilizer.

Imhoff [41] reported that at the end of 1932 there were 240 towns in Germany with two-story tanks and 70 with separate digestion tanks; and that the separate-digestion principle is being adopted rather than the two-story, since the latter type of tank cannot be heated.

More than the usual amount of interest has been shown in problems relating to the heating of digestion tanks and heat losses therefrom.

T. Nutter [42] described heating separate digestion tanks at Rockdale. Live steam is admitted from pipes opening into the tank bottom at the inlet end, the steam mixing with the whole of the sludge, which is kept in circulation. A temperature of about 70° F. is maintained.

C. E. Keefer [43] reported the heating of separate digestion tanks at Baltimore by direct addition of hot water and by circulation through coils. Less total heat was required and 24 per cent more gas was produced when hot water was circulated through coils. With the direct addition of hot water, the sludge withdrawn contained 15 per cent more solids.

Rudolfs and Miles [44] investigated heat losses at Freehold, N. J., from a digestion tank surrounded by an earthen embankment. Gas production amounted to 0.8 cubic feet per capita when the tank was maintained at 94° F. With a ground temperature of 54° F., 33.4 per cent of the gas was required to heat the tank.

Kraus [25] reported on operation of heated separate sludge digestion tanks at Peoria, Illinois, which received settled and activated sludge. Digestion for 10 days at a temperature of 90° F. resulted in 40 per cent reduction of volatile solids; satisfactory separation of supernatant liquor and sludge was obtained in secondary digestion tanks; the amount of gas per pound of volatile solids added in single-stage digestion was 8.3 cubic feet and with two-stage digestion, 14.4 cubic feet for both stages.

Monthly operating records from Springfield, Illinois, with activated sludge and from Grand Rapids, Michigan, with plain sedimentation and from Aurora, Illinois, with trickling filters (but no final settling tanks) were as follows:

Plant (1933)	Gas in Cubic Feet Per Capita	Gas Per Pound of Volatile Solids Added
Grand Rapids	0.88	7.46
Aurora	0.56	13.60
Springfield	0.60	8.52

Further data from Springfield, Illinois, for the year 1933 show that a 180 h.p. gas engine has been operated on sewage gas at Springfield. During the year the engine was operated partly or wholly on 355 days.

The installation, including engine and its auxiliaries and gas holder, cost $10,840, and the operating costs have amounted to $1,136 for the year. With fixed charges at 10 per cent, the total annual cost has been $2,220. The saving in power has been 635,000 k.w.h. which at 1 cent per k.w.h. amounts fo $6,350, resulting in a net annual saving of $4,130.

For the year the engine has produced about 65 per cent of the power needed for aeration, the monthly average reaching as high as 94.3 per cent for January, 1934.

These results have been obtained with an average air consumption of 1.02 cu. ft. per gallon of sewage, a connected population of 70,000, an average flow of 6.7 m.g.d. and an average gas production of 0.6 cu. ft. per capita per day.

Activated Sludge

Plant construction during 1933 indicates that the activated sludge process remains the tried and approved method for producing the highest quality effluent.

Howson's paper at a meeting of the Institute of Chemical Engineers in London, May, 1933,[45] points out that almost without exception the large cities of 500,000 or more population in United States have selected activated sludge as their type of treatment. Imhoff, in his paper before the same Institute, shows that there are 13 activated sludge plants serving about 900,000 population in Germany.

The plant designers have lost through the death of T. Chalkley Hatton and J. L. McClintock two of their highest class men. Hatton will be remembered for his pioneer work at Milwaukee, while McClintock was actively engaged in the design of New York's Wards Island plant.

New Plants.—Two exceptionally large plants, the Wards Island New York (180 m.g.d.) and the Easterly Plant at Cleveland (123 m.g.d.) are under construction. The Easterly Plant at Cleveland will be watched with interest to see the results of the extensive use of aluminum and its alloys in resisting corrosion.

Milwaukee [46] is planning an addition to the activated sludge plant. The present capacity is 85 m.g.d. The proposed addition will be for 70 m.g.d. Indianapolis [47] is also contemplating an enlargement to the plant.

A plant is being built at Marlboro, New Jersey, using a brush aeration process as developed by Row Engineers, Inc.[48] At Sparta, Illinois,[49] an Imhoff tank contact-filter plant was rebuilt and converted to an activated sludge plant, in order to treat sewage containing rayon mill and creamery wastes.

In England at Mogden, Middlesex County,[50] an activated sludge plant is being constructed under the direction of John B. Watson to serve a population of one million persons. This will be by far the largest activated sludge plant in England. Two new bio-aeration plants are under construction at Sheffield [51] to replace obsolete plants at Woodhouse and Woodhouse Mill. The Simplex works at Halifax are being increased from 20,000 gallons per hour to 70,000 gallons per hour. A new Simplex surface aeration plant went into operation in May, 1933, at Coatbridge, Scotland.[52] This has a capacity of 4½ m.g.d.

After a number of years experimentation, Osaka, Japan,[53] is now building two large activated sludge plants, the Tsumori plant serving a population of 734,000, and the Ebiye plant serving 451,000. These plants are designed on a 53-gallon per capita per day basis, and the depth of the aeration tanks, using diffused air and spiral flow, will be 15 feet. The aeration time will be about 5.5 hours.

Mendelsohn,[54] describing the sewage works at Tokyo, Japan, gives some figures comparing the results of the diffused air system against the mechanical paddle wheel system (Sheffield) showing that the mechanical activation produced a somewhat better effluent than the diffused air. These results should be studied with some care as the capacities of the two types of plant were widely divergent, the mechanical plant being 1.2 m.g.d. while the diffused air plant was only 0.037 m.g.d.

Paris, France, finding itself handicapped for more land to dispose of the sewage by irrigation, has turned to experimenting with activated sludge. At Colombes they have a 1.0 m.g.d. plant using diffused air from perforated pipes, and a 1.25 m.g.d. Simplex plant. At Montmesly, the Sheffield method is used in a 1.0 m.g.d. plant.

Theory and Practice.—Whitehead and O'Shaughnessy [45] have presented an interesting paper on sewage disposal, and show the development of activated sludge from its earliest beginnings.

Spode,[55] discussing the aeration requirements of activated sludge plants, points out four cardinal principles which must be embodied to provide successful operation:

(1) Intimate mixing of the sludge and sewage during the aeration period.
(2) The preservation of aerobic conditions in the plant.
(3) Storage capacity in the plant to deal with peak loads.
(4) Systematic discharge of surplus sludge under controlled conditions.

The mechanism of the activated sludge process, which has been explained by a number of theories in the past, from an absorptive, enzyme action, or biologic action standpoint, has been explained by a new theory propounded by Professor E. C. C. Baly of Liverpool [56] involving neutralization of electrical charges on colloids. The theory does not however explain the action of the substances in true solution.

Dr. Calvert,[57] of the British Water Pollution Research Board, mentions an interesting use of the methylene blue test. His studies indicate that if the time of reduction of the activated sludge is one hour, and the reduction of the sewage-sludge mixture is not less than 24 hours, the sewage is regarded as being fairly well purified.

Reducing Operating Costs.—Perhaps more effort has been directed to the cutting down of operating costs than to any other line of endeavor connected with activated sludge plants.

The combination of diffused air and mechanical devices such as Imhoff first used at Essen Rellinghausen has been utilized in a number of plants described in last year's report.

Newark, New York,[58] is one of the more recent installations utilizing paddle wheels and air diffusion.

Besselievre,[59] in a study of plants of this type, reported that from 11.0 to 15.8 horsepower per million gallons were required for the paddle wheels, and from 6.3 to 17.2 by the air diffusion, making the total input per million gallons from 17.3 to 33.0 h.p. It is pointed out that this type of installation offers flexibility of control in air application that is not obtained in other plants, such as shutting off the air diffusers at night during periods of low flow, the paddle wheels being sufficient to provide agitation; and also providing for "tapering off" diffused air so that heavier doses can be applied to the influent and lighter doses toward the effluent end of the tanks.

At Collingswood, New Jersey,[60] Dare reports a substantial saving in operating cost, by using a 10-minute aeration period followed by a 5-minute rest period, and repeating this cycle throughout the entire 24 hours. The process is automatically controlled by a program clock.

The large North Side plant of the Sanitary District of Chicago has operated with an exceptionally low air requirement, averaging 0.42 cu. ft. per gallon in 1932.[61]

Hoskins [62] at the Pennsylvania Sewage Works Association meeting "wondered if on the whole we were taking economic advantage of stream recovery capacity to its maximum safe limits."

In line with this, the plant at Lima, Ohio, is operated as a complete activated sludge plant in summer, and in winter only with sedimentation processes.

Pre-Aeration.—Pre-aeration is becoming more and more popular. With its first introduction it seemed limited to Imhoff-tank sprinkling-filter plants, but now is used in quite a number of activated sludge plants. The advantages of applying air ahead of primary settling tanks, have been pointed out by Roe [63] and Veatch,[64] who state that sedimentation is improved, grease is liberated, and odors are blown out. It might be well to point out, however, that using aeration to blow out odors should be approached with caution, unless provision is made to trap and deodorize the gases blown out. Unless this is done nothing in odor reduction is gained except possibly a "freshening" effect in the sewage. Roe calls attention to the fact that design of pre-aeration devices is not definitely standardized and that the time of aeration varies from 10 to 30 minutes, and the amount of air from 0.05 to 0.10 cu. ft. per gallon. With plate diffusion, practice indicates that 20 to 30 square feet of plate area per million gallons are used, and the air is applied at about 3 cubic feet per minute per square foot of plate area.

At Osage City, Kansas, Veatch [65] has recently remodeled an old septic tank-contact filter plant and added pre-aeration using 10 minutes contact with diffused air from a grid of porous tubes.

Stanley [66] has added pre-aeration treatment ahead of his primary settling tanks of the San Antonio activated sludge plant to de-emulsify grease.

At Golden Gate Park, San Francisco, pre-aeration using tube diffusers is provided in an activated sludge plant, before the return of activated sludge.

Pre-aeration is also used at the Stahnsdorf plant, Berlin,[67] and at the two plants now being built at Lancaster, Pennsylvania.

Activated Sludge Disposal.—In the past year a great deal of interest has been centered in controlling the condition and depth of sludge in settling tanks.

Sludge blanket depth detectors are described by Vermilye,[68] Donaldson [69] and Bloodgood.[70] In the new plants being built at Lancaster, Pennsylvania,[71] sludge level detectors are installed in the final tanks. Hoffman,[72] at Morristown, New Jersey, using a photoelectric cell has devised an arrangement which automatically opens or closes valves which regulate the sludge level.

The high moisture content of excess activated sludge has always been a source of annoyance to the plant operators who have to dispose of it either by digestion, filtration, or other means.

Haseltine [73] has discussed the effects of returning excess activated sludge to the incoming raw sewage and points out that this practice increases the loading on the aeration processes, causing sludge to accumulate faster in the aeration tanks, and results in a larger proportion of light floc in the aeration tanks. In spite of this, however, this practice is in general use which indicates that the plant operators recognize it as the best method available in most of the plants.

Goudey and Bennett [74] have reported a sludge concentration method at the Los Angeles experiment station, where a portion of the mixed liquor from the main aeration tanks is diverted to a continuously operated mechanical clarifier. Chlorine is applied to the top layer above the sludge blanket to maintain one p.p.m. excess. The chlorinated effluent then is returned to the main effluent flow from the regular clarifiers. Sludge is withdrawn once daily. By this method they obtain a sludge of 94.8 per cent water content. To produce heavier sludges they weight the sludge down with inert material such as oyster shells, magnesite and other substances. They have produced sludge as low as 76 per cent moisture by this method. As yet the costs remain to be determined.

At the Barnsley Sewage Works in England, Bell [75] has had difficulty in drying activated sludge on drying beds. Experimenting with insoluble particles of gritty material (sand) applied to the sludge he found he could separate two thirds of the original water in three hours or less, allowing sufficient time for settlement. He claims to have had far better results with sharp-grained materials than with smooth-grained.

Kersaw [76] at Epsom, England, has devised a novel scheme for disposal of excess activated sludge, by applying it to growing coarse water grass about a foot high. This method gives little trouble from odors or flies.

Sludge Bulking.—Ridenour's [77] studies of bulking at one of the New Jersey state plants using brush aeration, showed that the suspended solids concentration must be kept low to prevent bulking, and that the sludge index frequently used at other plants was of no value at this particular plant.

R. N. Clark's [59] experiments indicate that ferric chloride can be used with success in controlling bulking of activated sludge. The amounts of $FeCl_3$ used varied to a maximum of 83 pounds per million gallons. The best results were obtained when a small amount of air was introduced just after the chemical was added. The air increased the size of the floc and maintained the iron in a ferric condition. Throughout the experiment the pH value was unaffected.

Use of Activated Sludge Plant Effluents.—The high quality of activated sludge plant effluents is utilized in Golden Gate Park, San Francisco,[78] where it is used for irrigation, and in lakes and small scenic waterfalls.

A novel use is made of the effluent at Grand Island, Nebraska, where a public skating pond has been built, and the plant effluent is allowed to freeze in it.

At Herington, Kansas,[79] a contract has been made between the Rock Island Railroad and the city, to use the plant effluent for boiler water. The revenue derived from this is to be used to retire the loan granted by the government.

Legal and General.—Any reference to activated sludge progress would not be complete without mentioning the important decision handed down February 7, 1933, by Judge F. A. Geiger [80] of the U. S. District Court of Milwaukee, wherein he upheld the validity of the patents of Activated Sludge, Inc., who had instituted suit against the City of Milwaukee. The case has been appealed and was argued before the U. S. Appellate Court in Chicago in November. (A decision sustaining Judge Geiger was handed down March 2, 1934.)

The ruling of Judge Lindley of Chicago in a similar suit against the Chicago Sanitary District is being awaited with a great deal of interest.

Chlorination *

Chlorine continues to serve as an adjunct in sewage treatment and its application has been extended during the past year. Aside from its use in disinfection, its application for destruction and prevention of odors has been the most important and of the broadest interest. Next in interest has been the application of chlorine to reduce the rate and the amount of oxygen consumption of effluents in streams and also for the purpose of suppressing aquatic growths in stream beds below treatment works. On this score seasonal chlorination is serving to prevent nuisance and unsightly conditions along streams in summer when the dilution and oxygen supply are somewhat (not markedly) below requirements for an unchlorinated and more rapidly decomposing effluent.

Disinfection.—Concerning the mechanism of disinfection of sewage and effluents, results of the investigation at the New Jersey Sewage Experimental Station by Rudolfs and Ziemba [81] are to be published shortly in the *Journal of Bacteriology*. Particular attention was paid to the

* Possibly by the time this review appears in print an important and thorough report on "Sewage Chlorination" which was presented before the American Public Health Association in October, 1933, by Langdon Pearse, as Chairman of its Committee on Sewage Disposal, will have been printed and distributed by the Association. As a thorough and careful review of the subject interested readers should examine and, if possible, secure a copy of this report.

effects of varying dosages of chlorine, the relative values of various chlorine compounds employed, the temperature and period of contact. In summary, the work revealed: That the rate of *B. coli* kill was greatest when the chlorine demand was lowest; time of contact following chlorine application is important only up to 2.5 minutes; chloro-peptones and chloro-proteins are neither inhibitory nor germicidal, but other chloro-products formed in sewage create a progressive reduction of bacteria with increasing time of contact, such as for instance in travel through trunk sewers and sedimentation tanks.

The above studies were made with a view to explaining the observed marked reductions of *B. coli* concentration in shore line waters of New Jersey as the result of sewage chlorination for bathing beach protection wherein chlorination, insufficient to produce residual chlorine in many instances, had resulted in unexpectedly high reductions of *B. coli* concentration in the bathing areas.

Prechlorination vs. Postchlorination.—In connection with Imhoff and plain settling tanks and those with mechanical sludge removal equipment, prechlorination is showing its superiority to postchlorination and is therefore being increasingly used [82] except in connection with septic tanks. At Dayton, O.,[83] for instance, Imhoff tank performance has been materially improved showing an average increase in B.O.D. reduction of 16 per cent and other advantages, such as scum reduction in the vents and less suspended solids in the influents. Dayton continues to use the lime-chlorine process. At Baltimore, Md.,[84] and elsewhere it has been established that prechlorination improves sludge digestion rather than the converse.

Prechlorination was established with satisfactory results in odor control during the late summer at Cleveland's Westerly Plant; for some years it has been effectively used at the Southerly Plant, consisting of Imhoff tanks and sprinkling filters.

The Los Angeles County Sanitation District [85] continues to operate 8 chlorinating stations on its extensive sewer system to provide prechlorination for odor control. But, the increased efficiency and capacity of the activated sludge type treatment plant, as a result of maintaining the sewage in a fresher condition by the practice of prechlorination, has been an effect of possibly greater significance.

Stream Improvement.—Studies of the stream receiving settled and chlorinated sewage from the treatment plant at Chapel Hill, N. C.,[86] covering a period of four years, constitute an important contribution to the literature as to the effect of a chlorinated effluent on the receiving stream. The dissolved oxygen in the stream was increased and the B.O.D. was decreased markedly by chlorination. At the critical point 3000 feet downstream these figures were 147 per cent and 24 per cent

respectively. Farther downstream conditions with and without chlorination were approximately equal.

At Downer's Grove, Ill.,[87] chlorine applied to settled sewage and sprinkling filter effluent has had a satisfactory effect in improving stream conditions including elimination of fungus growths. Chlorination of the two effluents resulted in a dissolved oxygen content of 3.5 p.p.m. at a point 1000 feet below the outfall whereas on occasions during the summer when chlorination was suspended the dissolved oxygen in the stream practically disappeared.

In an unpublished experience, a serious growth of *sphaerotilus* in the stream receiving effluent from the Winston-Salem, N. C., chemical precipitation plant was controlled by chlorination of the effluent. Likewise, the dissolved oxygen content in the stream was maintained and the B.O.D. was definitely reduced. The use of chlorine for stream improvement at Winston-Salem is, in consequence, to be established as routine summer operation.

Profuse growths of green algae and other vegetation in streams receiving biologically oxidized effluents have come to be a problem of increasing importance. Such growths choke the flow, die and decompose to create a nuisance—all the result of high efficiency sewage treatment. The unsightly condition of streams so affected has been the source of complaint and suit by riparian owners.

At Fostoria, O., effluent chlorination has controlled such growths with marked improvement in stream appearances. The residual chlorine dissipates after a short distance of stream travel and fish thrive below the zone of residual chlorine, which extends a short distance below the plant. Rooted vegetation is not destroyed.

A large tonnage of bleaching powder (chlorinated lime) was applied to sewage entering Coney Island Creek, a tidal estuary near Coney Island, N. Y., in which an abundance of hydrogen sulphide was produced from sulphates in sea water by biological attack. The purpose, and its realization, was that of holding sulphate splitting in check by reducing biological activity. The procedure was admittedly a temporary expedient, to relieve a nuisance in a thickly populated area until permanent diversion of the sewage can be arranged for the treatment was effective. In previous years intermittent chlorination of the creek proper, followed by nitrate (Chile saltpeter) added to the sewage, has been utilized with some degree of success for providing an artificial oxygen supply to satisfy biological requirements and prevent sulphate reduction.

Chlorination of Sludge and Foaming Control.—Rudolfs,[88] in studies made at the New Jersey Sewage Experiment Station on the chlorine absorption of sewage sludge, found the absorption to be quite rapid for the first half hour, during which time 80 per cent of the organisms were

destroyed. After 6 hours 97.8 per cent were killed, whereas the remaining 2.2 per cent were highly resistant to chlorine attack even after 24 hours. The modern conception of the process of chlorination—first oxidizing those substances in solution capable of oxidation; second, the attack of finely divided particles (colloids, bacteria, etc.) and, finally, the difficult penetration of the coarser, more resistant particles of the suspended organic matter—was thereby strengthened. Likewise the theory that oxygen demand reductions come about by a combination of chlorine with organic bodies seemed to be supported.

Chlorine was found to control foaming of Imhoff tanks at Stockton,[89] California. Application of moderate dosages to the raw sewage entering the Imhoff tanks for 16 hours a day (6:00 a.m. to 10:00 p.m.) controlled foaming after 10 days of such treatment. As a consequence the quality of tank effluent improved.

Improved Chlorine Dosage Regulation in Odor Control.—An interesting method of regulating chlorine dosage in odor control practices has been developed by Griffin.[90] Since the standard methylene blue stability test is a measure of the concentration of reducing materials present, the length of time required for disappearance of the blue color in a chlorinated sample of sewage is also the time interval during which no odors from septization will appear, provided no seeding material of consequence enters the sewage beyond the point of chlorination. Slight development of sulphides will cause the blue color to fade quickly and therefore the test is an indicator of sulphide production. By this means of control, the chlorine requirement for odor control has been more scientifically and economically fixed.

A constant source of odor nuisance in the grease separating room at the Erie, Pa.,[91] sewage treatment plant has been eliminated by the application of 1.5 to 2 lbs. of chlorine to the grease separating tank, handling 5000 gallons of skimmings daily from the clarifiers. The required residual chlorine in the grease-water mixture was about 1.4 p.p.m. at a cost of only 11 cents per day for chlorine.

Production of Chlorinated Iron Coagulants.—Although some plants in recent years have experienced difficulties in manufacturing ferric chloride at the point of use, there are now several plants, notably that at Oklahoma City,[92] Okla., which are successfully making ferric chloride using tin cans as a source of iron. The cans are placed in a concrete tower with a chlorine solution entering at the bottom. The mixture of ferrous and ferric chloride solution which flows from the top is completely oxidized to ferric chloride by a further addition of chlorine as it flows through a pipe line to the point of application. By adding the "home-made" ferric chloride, up the sewer, odor control and floc formation are effected enroute to the plant. A new chemical precipitation

plant under construction at Birmingham,[93] Ala., will employ chlorine in the production of chlorinated copperas as a coagulant, for reduction of B.O.D. and disinfection.

At Newark, N. Y., demonstrations were conducted wherein heavy applications of chlorine were applied as a coagulant on mixed crude solids and wasted activated sludge returned to the crude sewage for resettling in the preliminary settling unit. Recirculation of the superchlorinated solids is said to improve sedimentation and reduction of oxygen demand, but no operating data on the process have been released for publication. A portion of the superchlorinated mixed sludges was dewatered on vacuum units without additional coagulant being required. The process is under development by the Diamond Alkali Works. The process was later tested on a larger scale at Rochester, N. Y., but has not been adopted for plant expansion.

Although chlorine has been reported by Simpson [94] and others to be but slightly successful in destroying *Psychoda alternata* breeding in sprinkling filters, more recent experiences at Allentown, Pa. (yet unpublished), indicate that heavy chlorination of the filters every ten days seems effectively to control fly breeding.

Chlorine Demand Determination.—Determination of chlorine demand (chlorine required to oxidize reducing substances present and leave a slight residual of excess chlorine) because of its increasing usefulness and value, has received attention during the year. Where the volume of sample is limited or the work must be done rapidly, an empirical procedure of titration is employed. In this, a standardized neutral or slightly alkaline hypochlorite solution is employed and the endpoint is determined by a spot-plate test using orthotolidin reagent. As a field-test it is satisfactory.

A more exact test [95] has been utilized, in which a preliminary rough titration is employed to reveal the approximate demand, whereupon the exact demand is determined by utilizing a series of samples of 500 c.c. portions of sewage to which are added increasing chlorine dosages during stirring. After five to ten minutes of contact a small volume of each sample is tested for the presence of residual chlorine. That dosage which gives a slight but positive residual chlorine test represents the chlorine demand. For greater exactness (hardly justified on practical grounds) the residual chlorine value, determined quantitatively, is deducted from the total applied to arrive at the minimum chlorine demand.

In England a very exact laboratory test [96] for determining chlorine demands of sewages has been suggested but on practical grounds such refinement of the test is of questionable justification. Chlorine demands of sewages and effluents vary from hour to hour and the method of collecting and handling the sample to avoid expulsion of hydrogen sulphide

is immensely more important than undue refinement of the determination. Further investigations of procedures for chlorine demand determinations are, however, justified to evolve a standardized procedure for practical field use and possibly another, of greater precision, for laboratory use.

Improving Sludge Density and Reduction of Supernatant Liquor.—The reduction of the water content of crude solids and surplus activated sludge added to separate sludge digestion tanks has been an important problem in making more successful and economical the operation of activated sludge plants. The ill effects from the return of large volumes of supernatant digester liquor to the crude sewage or aeration tanks at activated sludge plants seem fair to be largely eliminated by an expedient developed by Goudey at the Los Angeles, California,[97] experimental station. Instead of wasting excess activated sludge to the crude sewage for concentration with crude solids in primary settling units, the Los Angeles method is to concentrate the surplus sludge in a separate tank and to reduce the water content to 95 per cent. To hold the concentrating sludge in an aseptic condition (avoid bulking) chlorine is applied to the upper strata of liquid in the concentrator tank in amounts equivalent to roughly 25 lb. per m.g. of sewage passing through the plant. The thickened sludge is then transferred directly to the digesters, thereby reducing the total volume of (activated plus crude) sludge by 15 to 36 per cent.

At Phoenix, Arizona, the Los Angeles scheme has been put to use by Travaini with results (unpublished to date) surpassing those observed by Goudey and Bennett, thus again proving that supernatant liquor in appreciable volume is toxic to the activated sludge process.

Reducing Industrial Waste.—The value of chlorination and especially the ammonia-chlorine process in paper and paper products plants has been definitely established and expanded. Chlorination of white-water,[98] ordinarily going to the sewer, allows the return of this waste product to the process without biological difficulties previously encountered when attempting such practice. Savings to the manufacturer result, and the "closed system" scheme of operation is reducing stream pollution—or loadings on treatment plants—created by open systems in such plants. The future in waste and stream pollution curtailment may likely find other manufacturing processes subject to conversion to "closed systems" with profit to all concerned.

Mechanical and Chemical Processes

Interest continues unabated in chemical precipitation methods for sewage treatment. Two distinct trends are to be noted: one where chemical processes are intended to be self-contained and independent of

biological processes; the other where chemical methods are being employed as aids to biological processes, for reasons of nuisance abatement or for increasing the efficiency of existing investments.

Of the self-contained chemical processes there are very few plants in full scale routine operation in this country today. At Providence, R. I., lime and bleach continue to be used in treatment of about 35 m.g.d. in order to get the maximum efficiency out of sedimentation facilities. This method of treatment, although practiced for several years, is regarded as more or less of a temporary expedient pending the completion of an activated sludge plant, the preliminary units of which are now used for the present treatment. The sludge at Providence is dewatered by plate filter presses and the cake dumped in lower Narragansett Bay.

The Winston-Salem, N. C., plant constructed in 1927–28 continues to use the Landreth electrolytic process. The treatment is essentially clarification with heavy dosage of lime. The alkaline sludge is dewatered by Wright vacuum filters and satisfactorily disposed of on dumps.

The plant at Ashland, Ohio, employs the Travers process whereby clarification is secured by the use of lime, ferrous sulphate and marl. A plant at Circleville, Ohio, employing the same process, was abandoned in 1931.

Of the chemical precipitation plants in actual operation on a plant scale, as complete processes, the one of most interest is at Dearborn, Mich., employing the Laughlin process. Announcement has been made within the past few months that this process has been taken over by the American Cyanamid Company. During November, 1933, the Dearborn operation, treating about 3.0 m.g.d. West Side sewage, has been under laboratory study by Dr. A. M. Buswell. The results of his tests are awaited with interest, since East Side sludge was excluded from West Side sewage throughout November, 1933. Earlier tests on sewage only have been reported by Zack.[99] Dewatering of the sludge on Oliver vacuum filters has been practised at Dearborn. The alkaline cake is at present disposed of on dumps.

Status of Experimental Installations.—Completion of a six months test of the now well known Guggenheim process was announced several months ago. This demonstration plant of some 25,000 gallons capacity per day was operated continually at the North Side works at Chicago in parallel with the large activated sludge plant. The results announced by Mohlman[100] at Indianapolis in October and by Gleason[101] at New York in January indicate a very high degree of purification, namely, 91 per cent B.O.D. and 97 per cent suspended solids removal.

A test plant of the Lewis process was operated during 1933 at Atlanta, Georgia. This installation, with a normal capacity of 500,000 gallons daily, was designed, installed and operated under the supervision

of Alexander Potter, and Parsons, Klapp, Brinckerhoff and Douglas. The Lewis process involves the application of ferric chloride, lime, Cottrell dust and ferrous sulphate, in the order named. The test plant was operated during the period March 9 to Sept. 22, 1933, at various rates and with various combinations of chemicals. The results of operation have not been published.

An experimental plant employing the Streander process has been operated intermittently at the Northeast Works in Philadelphia during the past year and one half. This process involves the application of lime and ferrous sulphate with air mixing preliminary to settling the sewage solids. A rapid sand filter of the Blaisdell self-cleaning type is a feature of the installation.

No further developments have come to light in connection with the Stevenson process used experimentally at Palo Alto, California. This process involves chemical precipitation with ferric chloride in two or more stages with return of precipitated sludge to preceding sedimentation stages. It is understood that some experimentation has been made at other localities in California based on the Palo Alto methods, but so far no full scale plants are in operation.

A similar status of inactivity exists regarding the Miller-Koller process tried out at Elmhurst, Illinois, the Putnam process at Valparaiso, Indiana, the Cabrera process at Wilmington, Delaware, and the Diamond Alkali Company process, set up at the Cleveland Southerly Works, Newark and Rochester, New York.

Chemical Methods Auxiliary to Biological Processes.—There are several significant examples of chemical precipitation methods being used to improve the removal of suspended matter in sedimentation tanks, in connection with biological works. New structures for this purpose at the Plainfield, New Jersey, plant are expected to be in service in March, 1934. The situation here is that of an overloaded sprinkling filter installation with its various attendant evils. The new facilities provide for efficient flocculation of the sprinkling filter effluent with ferric sulphate before final sedimentation; the return of final sludge to the head of the plant with additional ferric coagulant at this point, as required. It is expected by these means to relieve the loading on the sprinkling filters and to improve the appearance and quality of the final effluent. Sludge will continue to be digested in separate tanks.

Further developments in the use of chemicals to supplement or augment the usual biological processes have been mentioned earlier in this report. The plant described by Hendon[104] for Birmingham County, Alabama, will utilize chlorinated copperas and lime during the summer. The Scott-Darcey plan of producing ferric chloride at Oklahoma City[94] is reported to be in use at Fairview, Perry and Enid, Oklahoma, and at

Essex Falls, New Jersey. Improved operation and abatement of odors have been reported.

Filtration of Activated Sludge Effluent.—The filtration of the effluent of activated sludge final clarifiers has been practiced at the Grand Canyon plant by rapid sand filters since 1926; at Tenafly, N. J., by intermittent sand filters since 1928; at Barrington, N. J., by rapid sand filters since 1931. The latest development along these lines is at Rockville Centre, N. Y., where vacuum filters were installed recently under the direction of Wm. Gavin Taylor, to rectify the failure of the original percolation beds to absorb the plant effluent.

The installation, completed the middle of last summer, was accepted by the Village February 3, 1934, after a successful 30-day test. During this test the clarifier overflow averaging about 2 m.g.d. and containing 33 p.p.m. suspended solids was filtered mainly by one filter unit of 500 square feet net area with occasional help from a second unit during peak suspended solids ranging up to 700 p.p.m. Suspended solids were reduced to an average of less than 2 p.p.m. The filters used are the Wright, string-take-off type furnished by the Municipal Sanitary Service Corporation. In operation the filters are first charged with about 800 pounds of paper (air-dry basis) as a 2 to 3 per cent suspension. The thick mat of paper pulp and sludge solids is continually repulped, drawn off, washed to get rid of the fine material and the washed pulp is returned to the filters for reuse. About 340 pounds of fresh paper has to be added to the system daily to replenish the fine material washed out and returned to the preliminary tanks.

A third vacuum filter unit at Rockville Centre is used to dewater a mixture of primary solids and excess activated sludge after conditioning with paper pulp and lime. About 55 per cent of the dry solids of the plant are handled on the filter and the remainder is handled by the separate sludge digestion tanks originally provided.

Vacuum Filters for Sludge Dewatering.—The use of vacuum filters for dewatering excess activated sludge has become well standardized as at Milwaukee, Chicago, Houston, Pasadena, Charlotte, High Point, Gastonia, and York Township using ferric chloride as the principal coagulating agent. Filter rates have varied from 1 to 5 lb. per sq. ft. per hour. At Hagerstown, Maryland, mixed activated and fresh solids have been filtered by Wright vacuum filters for some six months, using lime and paper pulp as conditioning agents. During this period the filter yields have averaged about 60 per cent of the stipulated 1.0 lb./sq. ft./hr. net sewage solids. Changes now effective provide for use of ferric chloride and lime in continuous two-stage mixers instead of batches, to prepare the sludge for filtration. Greatly increased filter yields and more dependable operation have resulted from the changed method.

During the past year considerable work on filtration of digested sludge has been carried on by Gascoigne at Cleveland. He has been operating an extensive plant at the Westerly Works to accumulate data for the design of the final plant.

In connection with the dewatering of sludge, particularly digested sludge, by vacuum filters considerable interest is being drawn to the operating results of an experimental filter at Baltimore, where methods of washing the digested sludge prior to filtration have resulted in very much higher yields and a striking economy in chemical requirements to prepare the sludge for filters. This method has been developed by Mr. A. L. Genter and the Baltimore experiments have been conducted under the supervision of C. E. Keefer and Herman Kratz, Jr., at the Back River plant.

The Genter methods are based upon the theory that amino acid and other ammonia compounds are responsible for the difficulties of conditioning sludge for filtration, and hence their removal by simple elutriation will result in lower chemical doses and more rapid filtration.

Dewatering Sludge by Evaporation.—For the past year and one-half the Sanitary District of Chicago has been experimenting on a large scale with equipment for the dewatering of filtered undigested sludge, prior to incineration. A large Oliver filter 16 ft. long by 11 ft. 6 in. diameter has been used for filtering undigested sludge, consisting mainly of activated sludge with a small proportion of settled solids. The filter cake has been dried in a rotary dryer, and the dried sludge burned in the fire-box of the dryer to provide heat for the evaporation of the water in the filter cake. The filter and dryer had a capacity of 20 tons per day of sludge on the dry basis. They were operated for about nine months and the conclusion was reached that the procedure was practical and preferable to digestion and drying. More recently a further improvement has been installed, for dewatering and incinerating the filter cake, consisting of a battery of three "Raymond" hammer mills through which the filter cake will be passed, together with the hot gases from its incineration, after further drying, and dewatered down to about 40 per cent moisture. A fourth "Raymond" mill is designed to dry down to less than 15 per cent moisture, whence the very finely divided sludge is blown into a pulverized fuel furnace and incinerated at a high temperature. All of the gases and evaporated moisture are to be passed through the high temperature zone of the furnace and effectively deodorized. It is expected that the dry sludge will have sufficient B.t.u. content to evaporate all of the moisture without the addition of coal, and also that the closed circuit for the gases and moisture, with passage through the furnace, will eliminate the possibility of odors, so often associated with dryers. The new drying and incineration plant will soon be in opera-

tion. This process is intended to be used for the disposal of practically all of the sludge to be produced by the great treatment works of the Sanitary District of Chicago.

Dewatering Sludge by Spray Dryer.—Included in the improvements of the Plainfield, N. J., plant now nearly completed and ready for service are novel arrangements designed to supplant the open sludge beds and make it possible to remove digested sludge independent of weather conditions. Arrangements as worked out by Mr. Downes include a vertical steel tank for thickening the sludge by flotation after dosing with alum, and a spray dryer as furnished by Industrial Associates, Inc. to dewater the thickened sludge from a moisture content of some 88 per cent down to about 20 per cent. The dried sludge will be either incinerated immediately or sold as powdered fertilizer material, according to the economics prevailing.

The Centrifuge Again.—There has appeared within the last year a new type of centrifuge with practically continuous operating characteristics, offered by the Sharples Company. It is designed particularly to thicken fluid sludges such as activated sludge prior to digestion or dewatering on vacuum filters. This machine was set up for a short time at Chicago and later field tests were carried out at Collingswood, New Jersey, on activated sludge. The results have not been published.

Stream Pollution

The paramount position of the public health interest has resulted in placing stream conservation programs very largely under the regulative and administrative control of health departments, with recognition in certain states of such secondary interests as playgrounds and fish and game protection. The relation of sewage pollution to the public health has been scientifically established and can be accurately stated in quantitative terms. The relative danger of nearby versus remote pollution; permissible loadings on various types of water treatment plants; standards of quality of waters for all types of use, domestic supplies, swimming pools, the growing of shell fish, etc.; can be established on the basis of biological facts and experimental data with a satisfactory degree of precision.

The problems of industrial waste pollution have not been so clearly defined, owing in part to their variety and complexity but chiefly to the fact that their sanitary significance is generally indirect and often remote or obscure. Coblentz [102] has discussed this question in a manner which is both analytical and constructive. Industrial wastes in general, and with but few exceptions, are less dangerous to community health than domestic sewage. In the development of a general stream conservation program, however, the relationship between the two becomes more and

more apparent. The "molasses slop" discharge from a distillery, for example, has a 5-day B.O.D. about 80 times that of domestic sewage. Such a waste in quantity necessarily makes heavy demands upon the self-purifying capacity of a stream. It forces itself into the picture whether we will it or not and no labored argument or refinement of logic is required to establish the position of this particular agency as a factor in the entire situation. In brief, industrial wastes complicate and in cases grossly aggravate the problems of stream protection and the processes of water purification, both natural and artificial, and of sewage treatment.

The author discusses the cooperative efforts undertaken by the industries of Maryland under the guidance of the chief engineer of the State Department of Health both in the Curtis Bay and Baltimore Harbor areas and in the upper Potomac River.[103] Specific treatments have been developed through experimental investigations for the wastes of tanneries, distilleries and chemical plants, and in many cases the industries have made the corrections indicated by these group investigations without legislative pressure and largely in their own self-interest.

Wastes from a chenopodium oil factory present a problem of peculiar interest. The product is used extensively in hook-worm treatment. It was found to be especially toxic to fish in a concentration of 50 p.p.m. These investigations also included studies of atmospheric pollution which we need not detail here. It is significant, however (and we are here reporting a research in the technique of handling such situations rather than in experimental waste treatment), that in these cases, also, important and costly modifications have been voluntarily undertaken in the interest of the general good. In this same connection a significant index of the present day tendency is the request recently made by the American Petroleum Institute to the Conference of State Sanitary Engineers for cooperation in a study of the wastes of the oil industry.

The activity of green plants as factors in the reaeration of polluted streams is well recognized but there is an unfortunate dearth of quantitative data. Calvert [104] has made a study in the White River below the outfall of the Indianapolis sewage treatment works which provides data of unusual interest. Diurnal variations in the amount and strength of the sewage coupled with variable stream flow made it possible to utilize the chloride concentration in the stream to determine the time of passage to Antrim, 6.3 miles below. During the summer season this time approximated 31.5 hours. A similar ingenious use was made of the observed time of passage of changes in stream velocity which likewise were of frequent occurrence and which were found to be synchronized over the stretch with a lag of about 7.5 hours. It was assumed that such changes pass rapidly through the pools but move over the riffles at ap-

proximately stream velocity. It would appear therefore that the stream spends about 7.5 hours on the riffles and 24 hours in the pools.

Despite this excellent opportunity for reaeration, the D.O. at the various river stations downstream frequently approached zero values. At the lower stations however, and particularly at Antrim, there was a definite diurnal variation of from less than 1 part at sun rise to from 5 to 7 parts in the early afternoon. This variation was not synchronous with the diurnal variations in sewage strength and is clearly the result of photosynthesis. The White River under these conditions becomes a most sensitive instrument for the quantitative measure of this phenomenon. It is to be hoped that the authors will take advantage of this unusual situation and will either work up their present data more completely or preferably make more detailed investigations next summer.

As an example of what might be done we note from their Table 1 and Figure 4 a total production of oxygen by photosynthesis averaging about 3 parts per million for 10 hours at a stream flow of 140 cu. ft. per second or approximately 945 lb. of oxygen per day. At a per capita ultimate B.O.D. of 0.22 lb., of which about one-fourth is required within the 30-hour period, this provides oxygen for stabilizing stream conditions in the presence of the untreated sewage of about 17,000 people. A somewhat more complete statement of the biological factors, particularly as to the extent and character of the areas of attached algae, might be found to provide a datum of fundamental value. This value would be greatly enhanced by a study of individual riffles, with particular reference to variations in types and to the effect of various light intensities.

A further important contribution of the same sort has been made by Ridenour [105] who has studied self-purification in a pond in northern New Jersey rather heavily polluted at its upper end by the treated sewage of a state institution. The total stream flow is capable of estimation with fair accuracy and the physical dimensions of the pond have been determined. The situation is such that the normal storage period in the pond varies from one to five days during the year, with mean values of approximately three days for both summer and winter. The pond has a mean depth of 8.9 feet with a maximum of 15 feet at the dam. The drop from the crest of the dam to the stream bed below is about 16 feet in a thin broken sheet.

The pollution loads, as represented by the 5-day B.O.D., varied according to stream flow from 5 to 27 parts per million, averaging for the year about 14.5. This value was reduced by passage through the pond to an average of 6.0, or separating summer and winter values, reductions of 66.5 and 52.5 per cent, respectively, were obtained. Mean summer temperature was 21° C. and mean winter temperature was 6.2° C.

The author computes from these data a value of the deoxygenation coefficient, K_1, of 0.168 for the summer period and the data permit a similar computation which gives 0.11 for the winter period. This use of experimental data for recomputing what we take to be a rather fundamental constant is perhaps objectionable. It would be preferable to assume the generality of the value of K_1 and to seek for some other explantation of the evident increase in the rate of self-purification.

The dissolved oxygen studies are of particular interest. The author does not give sufficient data to permit checking his computations, which lead him to the conclusion that the B.O.D. removal in the pond is 13.5 p.p.m., the loss in D.O. at the same time 3.1, leaving a net deficit of 10.4 to be furnished by reaeration or photosynthesis. The actual change in 5-day B.O.D. was in fact for this period 9.1 p.p.m. which, transferred to the ultimate value, represents about 15.0. Similar computations and apparent discrepancies occur in the treatment of the winter data. It is evident, however, that whichever value be selected, the pond has provided oxygen both winter and summer at a rate which has been most advantageous and which compared with rates quoted by the author from Mahr for various rivers and ponds in Germany is unexpectedly high.

From this point the author makes a most commendable effort to apply his deoxygenation and reaeration coefficients to stream conditions in general and shows in a most satisfactory quantitative fashion the advantages of the situation which he has studied as a self-purification mechanism, when compared with a normal flowing stream. Quantitative studies of this type are very much needed at the present time, especially in view of the development in Germany of storage systems on polluted streams with the specific object of facilitating self-purification. In the example before us, however, it would seem to be rather desirable to investigate certain possibilities which are not mentioned, namely, first that the pollution of this pond is primarily from the effluent of a trickling filter known to carry an unusual proportion of its unsatisfied B.O.D. in the form of a readily settleable material, and second that such an effluent might be expected to contribute nitrates in effective quantities. These two possibilities would account most readily for the apparent high values of deoxygenation and reaeration respectively.

Reference [103] was made last year to the general thesis which has been developed as a result of the experimental work of the U. S. Public Health Service group at Cincinnati regarding equilibrium between bacterial density, concentration of nutrient and the plankton population, of a polluted water. Hoskins and Butterfield [7] have now studied what they consider to be a special case of this general phenomenon, namely, the effect of the dilution of a polluted river by a considerable volume of the water of a less polluted stream. In general, under these circumstances there

is a pronounced increase in the total bacterial numbers following such dilution. An example is cited covering an 11 months' record of the Illinois River at the junction of the Kankakee. The increase in the numbers of coli-aerogenes ranged by months from 30 to 242 per cent, with only 2 months showing decreased values of 7 and 27 per cent, respectively. The 20° C. and 37° C. counts showed similar though less consistent variations. Data upon the Illinois above and below the confluence of other important branches, on the Chicago Drainage Canal at the confluence with the Des Plaines and at the mouth of the Scioto discharging into the less polluted Ohio, are similar, though less marked, and suggest a rather fundamental phenomenon.

A series of carefully planned laboratory experiments was made in an endeavor to investigate the mechanism of this phenomenon. Samples of the water of Mill Creek, a highly polluted stream flowing through Cincinnati, were stored at 20° and at 37° either undiluted or in dilutions with Cincinnati tap water in the ratio of 0.1 and 0.01. Plate counts at these two temperatures and determinations of the coli-aerogenes group were made at intervals. A fairly consistent result was obtained under all these varying experimental conditions, which may be summed up in the statement that there is an initial increase in the bacterial density under these circumstances, the ratio of increase being greater with the higher dilutions. Numerically the 0.01 dilution yielded about 9 times and the 0.1 dilutions about twice as many bacteria, per initial organism, as did the undiluted water itself. These general relations apply to the various temperatures of storage and to the bacteria as measured by the various types of tests.

A similar study was undertaken using waters of the Illinois River from six sampling stations extending from 166 to 288 miles below the head of the river. Dilution ratios of 0.5, 0.25, 0.1 and 0.05 were used in this series. The general result was almost identical but an additional fact of considerable theoretical interest appeared. Thus in water from the two most heavily polluted stations there was no increase in bacterial density upon storage of undiluted samples, nor did any increase appear in the series of diluted samples until diluted to 10 per cent in the case of the less polluted and 5 per cent in the more polluted water. Some increase occurred in the undiluted water from the third station, in the order of decreasing pollution, and the ratio of increase grew continuously with decreasing pollution of the sample. These results were likewise consistent as between 20° and 37° counts but storage was limited to 20° and coli values were not determined. There appears to be a natural tendency to bacterial increase during the storage of polluted waters which tendency increases with (*a*) the distance from the initial source

of pollution (extent of self-purification), (*b*) the extent of dilution of the sample previous to storage.

Before summing up the authors' conclusions we turn to two other investigations which appear to deal with the same general phenomenon. Butterfield [106] reports the result of an investigation upon the rate of increase in bacterial density during storage without dilution of four types of polluted water. Storage temperatures of 10, 20, and 37 degrees C. were employed and observations of the bacterial density curves were carried out over a period of 40 days. Plate counts at 20° and 37° and coli determinations were recorded. Butterfield also examined samples from each of his sources under both winter and summer conditions. The sources included two stations on the Ohio River representing different intensities of pollution, Mill Creek, previously referred to, and one of the Cincinnati sewers.

With a few exceptions, in the 166 samples studied, there was an increase in bacterial density at the beginning of the storage period regardless of the temperature of storage or of the season of collection. The proportionate increase for any type of sample was greater with lower initial bacterial density, but this rule does not apply as between waters of different types and intensities of pollution. With varying temperature of incubation the maximum was reached earlier but was not necessarily higher at the higher temperature. The author also studied the decreasing leg of the curve to which we need make no further reference at this point. With regard to the general fact of the initial increase upon storage he investigated many factors of possible influence such as the nature and size of the containing vessel, presence or absence of an air surface, exposure to light, occasional agitation of the sample, without developing any causative relations. Centrifuging or filtering the sample before incubation materially increased the tendency of the bacteria to multiply.

In a short contribution, Heukelekian [8] reports experiments upon a screened sewage, diluted with phosphate buffer water in ratios down to 0.5 per cent and incubated at 20° C. Results were obtained which are quite consistent with those already described, in particular as to the general relation between the ratio of increase and the dilution. The work is interesting because various other possible contributing factors were investigated in this case. The author paid particular attention to the initial D.O. content, the numbers and type of protozoa present, and the possible influence of phosphate or potassium ions. He finally rests his case upon the same basis as that adopted in the earlier Cincinnati work by Butterfield and Purdy, namely, that for any given concentration of nutrient material there is a self-imposed upper limit

of the bacterial density, and that with dilution this upper limit is not reduced as rapidly as the reduction in nutrient concentration.

Returning now to the general conclusions of the present work of Hoskins and Butterfield, the authors have returned to their thesis of a year ago in explanation of the phenomenon of increase following dilution; namely, dilution reduces both protozoa and bacteria by the same ratio but the combination of reduced numbers and shorter generation time of the bacteria as compared with the protozoa gives an advantage to the former, resulting in an initial and temporary increase.

This explanation is ingenious and harmonizes many of the experimental and field observations which have been accumulated at Cincinnati. In view of all the experimental facts, which have now been gathered, however, it seems to be inadequate. It appears to the reviewer that the fundamental fact in this series of events is that in a given medium the bacterial density reaches a self-limited maximum which is a function of the nutrient concentration. One cannot avoid the suspicion that this phenomenon (which is as yet without adequate explanation) underlies all the varied data herein reported. Neither Butterfield nor Heukelekian specifically referred the observed increases in their undiluted waters to a change in the protozoal population. The latter specifically disclaims this possibility. But the undiluted samples are clearly a part of the orderly and consistent scheme in which dilution is only one variable factor, as is beautifully illustrated in Hoskins' and Butterfield's Illinois River series. The practical effect of dilution, as the authors point out, is of great significance in our general theory of self-purification of streams, but the further studies which they suggest as being desirable will, we feel confident, eventually give us a much more satisfactory understanding of these important phenomena.

Stream survey activities are represented in two publications during 1933 of work done in previous years by the U. S. Public Health Service. Each of these is a re-survey, so that the data have the double advantage of representing a present-day situation and also a trend. In the case of the Ohio River a comparatively brief but quite satisfactory re-survey is reported by R. Crohurst.[107]

Since the 1914–16 survey there have been a number of changes in the hydrography, including two additional dams or a total of four between Cincinnati and Louisville, and an increase in the height of the dam at Louisville. There have also been material changes in populations and presumably changes in the extent and character of industrial waste pollution. The most striking change in the resulting condition is that associated with lower velocities, especially at the upper end of the section, and which has resulted in general in concentrating the self-purification. The net effect is that the immediate results of pollution

have been aggravated but the end results as measured at Louisville have been improved. The actual rates of bacterial decrease between Cincinnati and Louisville are quite similar to those observed during the earlier years although during the summer months the rate has been somewhat lowered. This observation accords with many others as to the effect of bacterial density upon the rate of decrease. The effect of dilution by a less polluted stream (discussed earlier in this section) is also recorded in this survey. The net effect of the canalization of the Ohio River, which is now completed, has complicated rather than simplified the problems of pollution and even the measurable improvement in bacterial pollution as related to water purification has been largely offset by additional plankton growths with accompanying shorter filter runs.

A second re-survey is that recently reported on the Potomac River at Washington.[108] Here again useful comparative data are presented between the conditions of 1913–14 and those of 1932. The most significant feature of this report, as it was of the earlier study, is the evidence presented of the very important rôle played by the so-called "flats" in the reaeration and self-purification of a heavily polluted stream. Tidal conditions result in an ebb and flow, over these extensive areas of shallow flowage of a considerable tidal prism twice daily. Extensive growths of reeds provide quiescent conditions and facilitate sedimentation. They also furnish a lodging place for enormous growths of plankton, which act as a most efficient purification mechanism.

The condition of the Potomac River at and immediately below Washington has evidently grown progressively worse as is clearly indicated in the comparative data. The efficiency of the flats as purifying mechanisms has become correspondingly more striking. At the point of maximum oxygen depletion just below the city, the average oxygen values were 15 and 26 per cent of saturation for the surface and bottom water respectively. Four miles below the values were 65 and 60 per cent, respectively. At the same time there was a reduction of bacteria, and of the coli-aerogenes group in particular, of about 99 per cent.

This situation probably represents one of the most striking examples recorded of an intense rate of self-purification induced by purely natural agencies.

A suggestive piece of research has been reported by Wooldredge and Standfast[109] relative to the biochemical mechanism of the oxidation of pollutional matter in streams. The authors repeated and confirmed the many previous studies showing the essential relation of bacteria to this phenomenon. They are, however, apparently unaware of the work of the Public Health Service group at Cincinnati, especially with regard to the significance of protozoa. An important suggestion however

comes from their observation that a suspension of *Ps. fluorescens*, killed with formaldehyde but retaining active indo-phenol oxidase and dehydrogenases, actively promotes the B.O.D. reaction. Their conclusions, relating to both sewage treatment and natural self-purification in streams, are: "The most important factor in sewage purification is a series of catalysed oxidation-reduction reactions, determined by bacterial enzymes present in either living or dead bacterial cells, or liberated by them into the fluid of the reacting system."

While this thesis probably merely states a fact almost self-evident to a bacteriologist, to whom most of the so-called biochemical reactions appear to be due directly or indirectly to enzymes, it does present a novel point of view to sewage investigators and, in its specific evidence as to the nature and distribution of the enzymes involved, opens up certain possibilities for further study. At present however the results should be taken as merely preliminary and suggestive.

Relation of Pollution to Water Supply and Shellfish

Citing two cases of his own experience in which sewage banned from a stream by a river pollution board had been disposed of through vertical drainage to chalk formations from which domestic water supplies were being pumped, J. F. Haseldine [110] expressed the essential thought that there should be cordial cooperation between river pollution boards, river conservancy boards and water supply authorities.

The year 1933 is conspicuous because of proposed action in conservation and equitable allotment of water resources. Studies of a scientific character upon which to plan such activities appear to have taken precedence over the usual stream pollution investigations and water purification improvements as they have been known. Inventories of private, municipal, State and Federal water supplies are being taken. Streams are being classified for drinking, recreation, industrial processing, waste carriage, etc. Purification processes are being modified to fit potable and industrial requirements. Streams are being stored to correct periodic deficiencies and floods. Ground water resources, fluctuations, chemical characteristics and possible control methods are being studied.

The Report of the Water Resources Commission of Maryland [111] emphasizes the absence of regulation in the development of water resources and the lack of continuous recording of stream flow. The Commission completed a comprehensive inventory of the water resources of Maryland and their use for all purposes. Fifty-three public water supplies are taken from streams of the State for a total population of 1,600,000 of which about 500,000 are in the District of Columbia. Of a total of 1,240 million gallons per day of surface water used, 252 m.g.d. are used for public water supply, 59 m.g.d. for industry and 928 m.g.d. for steam

power. Less than 14 m.g.d. are obtained from ground water. 183 m.g.d. of sewage, more than half of which is untreated, are discharged into the Chesapeake Bay and its tributaries. The Susquehanna River receives pollution from towns in Pennsylvania and New York. The Potomac and its tributaries provide outlets for considerable sewage and industrial wastes from Pennsylvania, Virginia, and West Virginia. The total minimum water requirements by 1950 are estimated at not less than 1,500 m.g.d. The Commission is given general powers to formulate a water conservation policy, to control the use of water and to provide for continuity of stream gaging and supervision of dams and other obstructions.

L. E. Meinzer [112] noting improvements in ground water development reminds us that about 6,500 public water supplies out of a total of about 10,000 in this country are derived from ground water and that from fifty to fifty-five million persons are served by these or by private wells. The writer describes progress in the technique of ground water investigation with reference to the work of the U. S. Geological Survey. Methods of estimating the capacity, rate of recharge and perennial yield of underground reservoirs, to prevent over-development and contamination have been developed, and hydrological surveys, eventually to cover the whole country, will furnish the basic data for future ground water projects.

M. Neisser [113] points out that increased water consumption in Germany has led to increased development of surface water supplies and of methods for the purification of surface waters. Imhoff's [114] theories on the practical application of the water-sewage-water cycle are discussed.

Streeter [115] summarizes and compares the results of investigations in an experimental water treatment plant and of observations on the operation of plants treating Ohio River and Great Lakes water. The relationship between the bacterial quality of a water before and after treatment appears to be governed by a fundamental law applicable to individual processes and to combinations of processes and analogous to the law governing adsorption phenomena. This law limits the average quality of an effluent obtainable by a particular treatment from a raw water of a given average degree of pollution, and, conversely, the maximum pollution of a raw water from which an effluent of specified average quality can be obtained. Pre-filtration treatment obtainable particularly by prechlorination, longer sedimentation, pH control of coagulation and long storage are indicated as methods of obtaining higher purification efficiencies. The author suggests increased attention to palatability and wholesomeness along with bacterial quality. The probable relationship of water-borne diseases to the presence of toxic substances and the desirability of more attention to pre-treatment and methods of protection by sewage and trade waste treatment are emphasized.

Crohurst [116] in his study of the Mississippi River found that the maximum effect of pollution was about 15 hours' flow below the sewers. This result is in agreement with previous stream pollution investigations. Summer rates of bacterial decrease were found to be from one to four times the winter rates, thereby confirming seasonal temperature effects on rates of natural purification found in the case of other stream studies.

Earle B. Phelps and Clarence J. Velz [117] made a more complete analysis of dissolved oxygen depletion in New York Harbor than has ever been previously attempted, to determine the Hudson River influence and the effect of shifting population and partial sewage treatment before discharge. The complex system of pollution, tidal circulation, re-aeration and self-purification were analyzed in an endeavor to arrive at a formula to express the relation between any assumed extent and distribution of pollution, the run-off of the Hudson River and resultant conditions in the Harbor.

George G. Nasmith [118] presented an admirable discussion of the chemical, bacteriological and biological changes which occur during the processes of natural stream purification and their application to sewage treatment devices. He emphasized the value of lakes and artificial ponds (German experience) for intensifying nature's water purification processes and directed special attention to the effects of concentrated pollution on water treatment devices (New York experience on the Niagara River, March, 1933) and the possible effect on water consumers as experienced along the Ohio River during the gastro-enteritis outbreak in 1930–1931.

The use of chlorine with or without ammonia and activated carbon is augmenting algae and micro-organisms control in lakes and reservoirs by copper sulphate and eliminating foul smelling basin sludge, odors and tastes in the water and dirty filter sand. Pre-chlorination is in general application to reduce bacterial load.

In the field of taste and odor control experiments of G. D. Norcom [119] at Chester, Pa., indicate economies in the substitution of "bleaching clay" for other methods of eliminating tastes and odors caused by industrial wastes, especially oil refinery and gas and coke works wastes. Dosages varied from 0.10 to 0.80 g.p.g. and averaged 0.34 g.p.g. The clay is said to aid the formation of a dense, strong, absorbent floc with alum which adsorbs chlorine, thus preventing decomposition of settled sludge. The average cost of treatment is 39 cents per million gallons with the cost of the clay at $16.00 per ton. The Report [120] of the Committee of the A. W. W. A. on Control of Tastes and Odors in Public Water Supplies summarizes experiences in twelve states in treatment for taste and odor control. Pre-chlorination is more widely used in New York State than any other single process. In Pennsylvania it is less

extensively used, and still less in Ohio. In the Middle West and South it is very little used. Possibly because of the peculiar advantage in the maintenance of higher residual chlorine values throughout the distribution system a large increase in the use of the chlorine-ammonia process is noted. Powdered activated carbon, either alone or in conjunction with other methods, is indicated as the most universally applicable taste and odor control measure now available. Potassium permanganate, super and dechlorination, chlorination for hydrogen sulphide removal and ozone are not used in sufficient installations to warrant their consideration as general control measures. Excepting ozone, each has been tried experimentally at some plants with little success. The great need of adequate taste and odor control tests and standardized specifications for activated carbon is apparent.

S. T. Powell [121] in discussing the enormous economic losses in this country caused by depreciation in the quality of water due to the recent drought shows that the Delaware River was found to increase in hardness from 25 to 30 p.p.m. at flows from 30 to 50 million cubic feet per second to 95 p.p.m. at flows from 4 to 5 thousand cubic feet per second.

The increasing demand for color, iron and manganese free water has developed numerous research studies to eliminate these undesirables from treated supplies for the industrial as well as the domestic consumer.

T. R. McCrea [122] has succeeded in removing color and organically bound iron from probably the highest colored water known. Water from the Great Dismal Swamp supplying Elizabeth City, N. C., after much experimentation, is being successfully delivered color and iron free to the consumer. Potassium permanganate in relatively small doses supplements chlorinated copperas treatment. The treatment is economical and practical.

Carl Zapffe's [123] complete review of the studies made in the removal of manganese of water since its earliest discovery seems to be a most helpful development of the subject that has appeared during the year. The studies are historically grouped. Concerning the most recent developments Zapffe deals with the experiences at Brainerd, Minnesota, where a water treatment plant was designed purely for manganese removal. The treatment comprises upward filtration through a bed of pyrolusite and subsequent filtration and aeration through a coke bed. Thence the water is discharged on an open sand filter. The final effluent is free of iron and manganese.

The most recent outstanding investigation of stream pollution in the interest of shellfish was made by Earle B. Phelps and Ellis K. Phelps.

As presented in the Proceedings of the 1932 Fall Meeting of the New York Sewage Works Association the object was to determine the geographical extent and intensity of sewage from specified sources over a

tidal area in which shellfish interests and bathing beaches were involved and in which pollution from other sources had also been present. By recording the time of sampling the waters in lunar hours (time after high tide), the results of bacterial examination at 8 selected stations made daily over a six weeks period could be averaged by two hour periods to obtain a picture of the influence of tidal circulation. Thus the individual effect of pollution from the various sources could be detected. Float studies were used to augment the interpretation of these data. During a second six weeks period similar examinations were made, while the sewage plant effluents from the specified sources were being chlorinated. As a seasonal control a third period was followed through under conditions similar to those in the first period. A study of the changes between period one and period two produced quantitative values in addition to the qualitative data obtained by the tidal variations. The intensity of pollution from the specified sources and its relative value with respect to pollution from all sources were thus determined for each of the eight stations over the basin. Twelve days after commencing chlorination of the settled sewage there was a 99 per cent improvement in the water at the harbor outlet as measured by the presumptive B. coli test. It is the opinion of the authors that shellfish should be grown in clean waters regardless of any degree of assurance that chlorination of the sewage would eliminate danger of disease propagation.

Carl E. Green [124] disclosed the rapid growth of the oyster industry in Washington, Oregon and California, notably in Washington, as a result of the importation of seed oysters from Japan. Details of necessary pollution control measures to provide for this type of oyster are outlined. The Japanese variety is more hardy and grows to marketable size in from 1½ to 3 years instead of from 3 to 5 years required by eastern oysters, principally because it passes far greater volumes of water through its gills than do the native or eastern species.

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A FORMULATION OF BACTERIAL CHANGES OCCURRING IN POLLUTED WATER

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Several years ago, in connection with an extensive laboratory survey of the Ohio River, conducted by the U. S. Public Health Service, under the direction of Dr. W. H. Frost, an intensive study was made of the progressive changes in bacterial content associated with natural purification of the river in a stretch 123 miles long, extending from a point immediately below Cincinnati to a point immediately above Louisville. Concurrently with these observations, a series of tests was made of the bacterial changes occurring in samples of the river water, when collected at the upper and lower terminals of this same stretch and stored in the laboratory at three different temperatures, 10°, 20° and 37° C. The primary object of these tests was to ascertain whether the course of bacterial changes observed in the stored samples tended to follow closely those which occurred in the river at about the same temperatures, so that the trend of natural purification could be traced by incubating samples of river water under standard conditions.

The results of these tests, which have been summarized recently in connection with a paper by Butterfield,* diverged in two respects from those of the river observations, which have been discussed fully in a general report † of the Ohio River survey. The bacterial content of the stored samples showed in every case an initial rise much greater than that observed in the river, and though this increase was followed in both instances by an orderly decrease, the latter was decidedly more rapid in the river under summer conditions than it was in the stored samples collected during the same period. During the winter period, however, the general trend of both the river and the stored sample curves throughout their phases of decline appeared to be fairly similar.

In the hope of clarifying some of these points, the writer undertook a mathematical analysis of the stored sample curves, somewhat parallel in scope and viewpoint to a similar analysis previously made of the

* C. T. Butterfield: Observations on Changes in Numbers of Bacteria in Polluted Water, This Journal, 5, 600–622 (July, 1933).

† A Study of the Pollution and Natural Purification of the Ohio River. II. Report of Surveys and Laboratory Studies, *Public Health Bull.* 143, U. S. Public Health Service.

curves obtained from the river observations.* The results of this analysis together with a comparison of the stored sample curves with those obtained from the river observations, are discussed in the present paper.

In order to provide a basis for illustrating both the general trend of the data and the results obtained from their mathematical formulation in connection with this study, two short tabulations of specimen data have been prepared, as shown in Tables I and II, in which the numbers of bacteria observed after various periods from the start have been expressed as their ratios to the initial numbers, the latter taken as unity.

TABLE I.—*Average Numbers of Bacteria, Expressed as Ratios to Initial Numbers, Observed in Samples of Ohio River Water Collected at Stations 475 and 598 throughout the Year, and Stored at Three Different Temperatures, 10°, 20° and 37° C.*
(48-Hr. Gelatin Counts, 20° C.)

Storage Period, Days	Ohio River Station 475, Storage Temperature			Ohio River Station 598, Storage Temperature	
	10° C.	20° C.	37° C.	20° C.	37° C.
0.0	1.00	1.00	1.00	1.00	1.00
0.17	.99	1.64	2.07	1.41	1.90
0.33	.99	3.79	3.04	2.58	12.30
0.83	1.71	3.91	2.96	—	—
1	1.92	3.86	2.04	16.40	56.20
2	2.73	1.92	.450	12.20	14.00
3	3.19	1.10	.221	—	—
4	—	—	—	4.64	2.65
6	1.03	.301	.104	2.37	1.54
13	.317	.173	.014	1.15	.55
40+	.094	.056	.009	—	—

Table I has been prepared from 20° C. gelatin count data given in full in Butterfield's paper, being based on averages of observations made throughout the year at three temperatures of storage, on samples collected at two stations in the Ohio River, one (Station 475) being located immediately below Cincinnati and the other (Station 598) immediately above Louisville. In Table II are shown corresponding ratios based on observations made directly in the Ohio River during the summer periods of 1914–15–16, in a stretch extending downstream from Station 475 to Station 598. The data for this tabulation have been taken from the

* For a full description of the latter analysis, see *Public Health Bulletin* 143, Section VI, part 2, pp. 278–335.

TABLE II.—*Average Numbers of Bacteria, Expressed as Ratios to Initial Numbers, Observed in the Ohio River Below Cincinnati at Various Times of Flow Below the Sewer Outlets During the Summer Period, April–November, 1914–15–16*

Mean Time from Sewer Outlets, Days	Ratio to Initial Numbers, in Terms of:		
	Gelatin Count, 48 Hours, 20° C.	Agar Count, 24 Hours, 37° C.	B. Coli Index
0.13	1.00	1.00	1.00
.30	.874	.846	1.03
.50	1.09	1.04	1.21
.73	1.09	1.07	1.11
1.05	.882	.712	.819
1.47	.843	.525	.447
1.87	.592	.310	.458
2.52	.326	.201	.199
3.47	.149	.101	.133
4.69	.052	.040	.066
5.83	.017	.012	.015
7.61	.012	.0073	.0046
9.12	.010	.0062	.0015
11.8	.0041	.0022	.0021
13.1	.0011	.0008	.0021
20.7	.0009	.0007	.0008

report * of the Ohio River survey to which previous reference has been made.

An inspection of these two tables shows a very similar trend of the data in every case, with a few irregularities which do not materially alter the picture presented. To indicate this trend more clearly, Figure 1 has been drawn from the results given in Table I, the curves being smoothed to permit more ready formulation, and being extended only for a period of 12 days from the start, which is sufficient to show typical sections of them well beyond their maximum crests. In this, as well as in the succeeding charts, the ordinate scale has been made logarithmic, in order to show directly the proportionate trend of the bacterial changes with time, which is represented by a linear abscissa scale. With this "semi-logarithmic" form of plotting scales, a strictly logarithmic rate of bacterial change would be indicated by a straight line, sloping upward or downward according as the change were in the direction of an increase or in that of a decrease.

* *Loc. cit.*, Table 117, page 288.

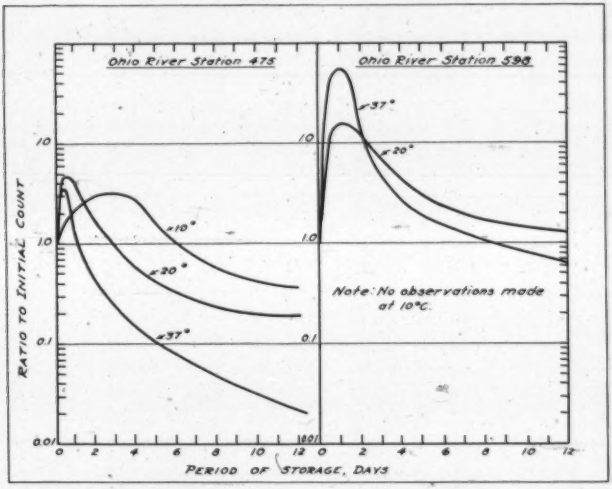

FIG. 1.—Progressive changes in bacterial content observed in stored samples of Ohio River water at stations 475 and 598, based on yearly average results from 48-hour gelatin counts at 20° C.

COMPARATIVE TREND OF BACTERIAL CHANGES IN STORED SAMPLES AND IN RIVER

In order to give an idea of the relative trend of bacterial changes observed in the stored samples and in the river, under comparable conditions of temperature, Figure 2 has been drawn, showing two curves, one based on the results obtained from samples collected at Ohio River Station 475 during the summer period and stored in the laboratory at 20° C., and the other from direct observations in the Ohio River below Cincinnati during the same seasonal period, when the mean river temperature approximated 20°. (See Table II.)

On referring to Figure 2, the two points of disparity noted by Butterfield* as existing between the trend of bacterial changes observed in the river and in the stored samples are clearly indicated. Thus the initial increase in bacterial content is shown to be much less in the river than in the stored samples, and the rate of decrease beyond the maximum point measurably greater.

* C. T. Butterfield: Experimental Studies of Bacterial Death Rates in Polluted Waters, *Jour. Bact.*, Vol. 16, No. 4, p. 257 (Oct., 1928).

In contrast to the divergence observed between the downward limbs of the river and stored sample curves under summer conditions was the substantial agreement noted between them under conditions of the winter months. This is illustrated in Figure 3, in which the descending limbs of the river and stored sample curves corresponding to those shown in Figure 2 have been drawn from data obtained during the winter period, when the mean river temperature was about 5° C. In order to bring the two curves to a roughly parallel basis of temperature,

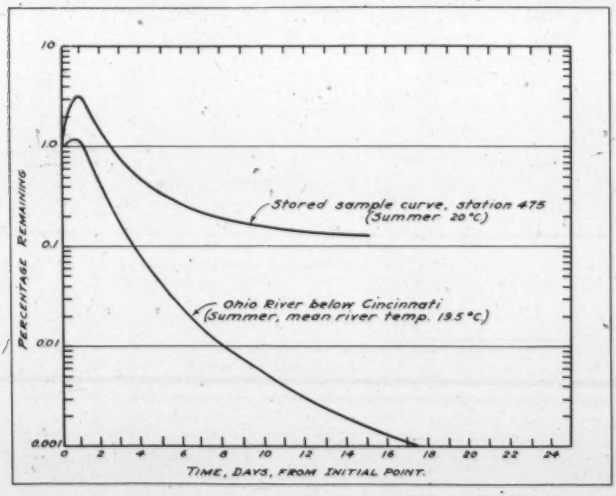

FIG. 2.—Comparative changes in bacterial content observed in stored samples of Ohio River water at 20° C. and in the Ohio River below Cincinnati under summer conditions at about same temperature.

the stored sample curve shown has been derived from tests made on Station 475 samples stored at 10° C., which was slightly higher than the corresponding river temperature, but sufficiently close for purposes of comparison. These curves are based on results obtained from standard gelatin counts made at 20° C., as in the preceding charts.

In Figure 3 it will be noted that the river and stored sample curves derived from the winter observations follow a much more nearly parallel trend than do the downward limbs of the summer curves in Figure 2, the river curve lying slightly above the corresponding stored sample

curve, rather than well below it, as in Figure 3. In undertaking to interpret this variance in the behavior of the summer and winter curves, the most important factor appeared to be the well-marked difference existing between conditions of flow and run-off in the river during the two seasons, which would be expected to influence progressive changes in the bacterial content of the river but to have no effect on those observed in the stored samples, as the nature and method of the latter tests would preclude such a possibility. During the greater part of the summer period, relatively low river stages prevailed, with conditions favorable to sedimentation. During the winter period, however, higher river stages and run-off into the river resulted in a minimum of sedimentation and, during a considerable part of the time, in a certain degree of

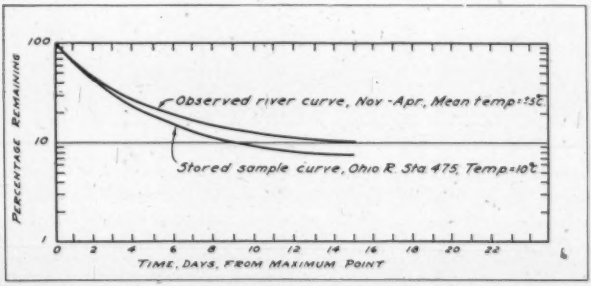

FIG. 3.—Comparative changes in bacterial content observed in stored samples of Ohio River water at 10° C. and in the Ohio River below Cincinnati under winter conditions at about same temperature.

channel scour and inflow, which tended not only to offset any sedimentation but also to produce at times an opposite effect.

A fairly reliable quantitative index of the variable effects produced on the suspended matter content of the river, and hence on its bacterial content, was found in the progressive changes in turbidity observed in the river during the winter and summer periods. As a rough measure of these changes, the monthly average ratios of river water turbidities observed at Station 598 to the corresponding turbidities observed concurrently at Station 475 and at Station 543, the latter being located about midway between the two terminal stations, were correlated with velocities and times of flow in the river as measured between the respective stations during each month.* Under winter conditions, these

* See *Public Health Bull.* **143**, pp. 149–153.

turbidity ratios were in general approximately equal to or in excess of unity, indicating either no change or a progressive increase in the suspended matter content of the river, whereas during the summer period, except for minor periods of local rains, the ratios were less than unity, indicating a decrease in the suspended content of the water in passing downstream. Under summer conditions a well-marked degree of correlation was shown between the ratios thus observed and the corresponding velocities and times of flow between the points of observation.

Assuming that a given degree of reduction in turbidity between two points in the river would be marked by a roughly corresponding reduction in the bacterial content due to suspended matter change, the ordinates of the observed summer curve of bacterial decrease in the river beyond the point of maximum bacterial concentration were corrected for this change, by dividing them by the turbidity ratios observed for corresponding times of flow. The resulting bacterial curve, if properly corrected, should show the extent of bacterial decrease in the river which might be expected to occur with no change in suspended matter. Although the assumption on which this method of correction was based was only a rough approximation to the truth, it appeared justifiable as a trial procedure in view of the fact that in artificial water purification processes involving sedimentation the physical reduction in bacterial content of a water tends to follow closely the concurrent reduction in turbidity.

The results of applying this kind of correction to the summer river curve are illustrated in Figure 4, in which Curve *A* is the uncorrected curve of bacterial decline in the river, Curve *B* the corresponding curve of turbidity decrease, and Curve *C* the corrected river bacterial curve, obtained by dividing the ordinates of Curve *A* by the corresponding ordinates of Curve *B*. For comparison with the corrected river curve, the descending limb of the stored sample curve obtained from samples of Ohio River water collected at Station 475 during the summer period, with a storage temperature of 20° C., has been drawn as Curve *D*. For periods of time ranging up to about 6 days, the agreement between Curves *C* and *D* is remarkably close. For longer periods, their proportionate divergence is more marked, though small in terms of actual numbers and much less than that which is shown between both of these curves and the uncorrected river curve, *A*. A similar plot based on parallel data obtained from the standard 37° C. agar counts gave substantially the same result, except for a slightly greater divergence between curves *C* and *D* for periods less than 6 days.

The foregoing results, when considered in conjunction with the nearly parallel trend of the winter curves in Figure 3, suggest very strongly that the higher rates of bacterial decrease observed directly in

the Ohio River during the summer period, as compared with those noted concurrently in the stored samples of Ohio River water, were due very largely to the effects of sedimentation of the suspended matter and bacterial content of the river. If the corrected curve of bacterial decrease represents an approximation to that of the true bacterial death rate in the stream, it would appear that this true rate probably is indicated very closely by the trend of the descending limbs of the stored sample curves, when considered as starting at about the point of maximum bacterial concentration.

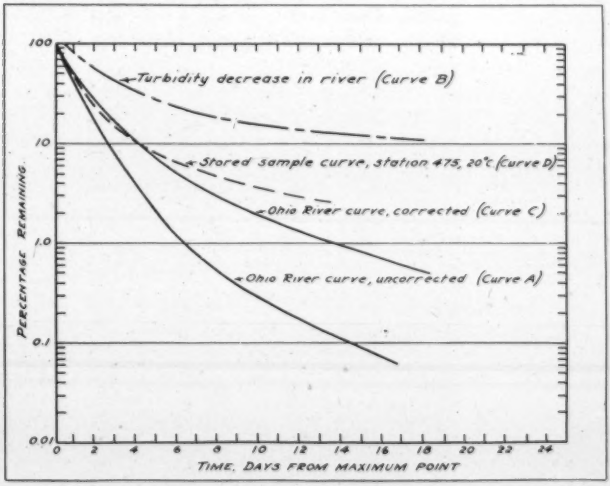

FIG. 4.—Correction of observed curve of bacterial decrease in Ohio River below Cincinnati (summer conditions) for effect of sedimentation; comparison of resulting curve with corresponding stored sample curve at about the same temperature.

It perhaps should be pointed out in this connection that the close agreement shown between rates of bacterial decrease observed in the stored samples and in the Ohio River below Cincinnati, when the latter have been corrected for turbidity change, would be expected to prevail only in streams like the Ohio, in which a fairly close correlation appears to exist between progressive changes in turbidity and corresponding changes in suspended matter and bacterial content. In some rivers, where this correlation is less definite, the agreement probably would be more remote, though hardly conceivable as being altogether absent.

Empirical Formulation of Curves

In undertaking to formulate the curves empirically, it was recognized that the initial stage of bacterial increase represents a transient and probably abnormal condition, due to a temporary disturbance in normal biological equilibrium, as suggested by Butterfield,* whereas the phase of decline in bacterial numbers following attainment of their maximum is characteristic of the normal process of natural purification, proceeding in this instance after equilibrium has been restored. For this reason, attention was centered first on the decline phases of the curves, which incidentally embraced by far the major portion of their entire span.

As it appeared *a priori* that the progressive decline of bacterial numbers observed both in the stored samples and in the river was due to some active suppressive force, or combination of forces, it seemed possible that whatever laws might govern the trend of such decline should be analogous to those which control more simple phenomena of the same kind, such as that of ordinary disinfection processes.

On referring to previous work on this phase of the subject, it was noted that König and Paul had shown as early as in 1897 that the mortality of bacteria in an unfavorable environment follows a regular course. Chick,† in her experiments on the death rate of *B. paratyphosus* when this organism was exposed to disinfectants, noted the earlier work of Ikeda and of Madsen and Nymán, suggesting that pure strains of bacteria tend to decline under disinfection at a logarithmic rate according to the formula:

$$\frac{1}{t_2 - t_1} \log \frac{y_1}{y_2} = K \text{ (a constant)}$$

or,

$$y_1 = y_2 \cdot e^{-K(t_2 - t_1)}$$

in which (y_1) and (y_2) denote the numbers of live bacteria surviving at times (t_1) and (t_2), respectively. She found, however, that with cultures of *B. paratyphosus* the death rate proceeded with a progressively diminishing value of (K), which she explained as being due to the higher resistance of certain individual cells to the action of a germicide than others. Scharff, in his study ‡ of the death rate of bacteria exposed to ultra-violet rays, likewise noted a diminishing value of (K) in the logarithmic rate of decline, after prolonged times of exposure.

A study of the downward limbs of the bacterial curves obtained from both the stored sample and the river observations indicated that they were of the same general trend as the curves obtained by Chick and by

* *Loc. cit.*

† *Jour. Hygiene*, **8**, 655 (1908); **10**, 237 (1910).

‡ *Jour. Infect. Dis.*, **10**, 305–320 (1912).

Scharff, both having a diminishing value of (K) with increased time. This tendency is illustrated in Figures 1 and 2 by the progressive decrease in the slopes of the stored sample curves beyond their maximum points, thus departing from a straight-line slope which would indicate a logarithmic decrease and constant (K). A further analysis of them showed, however, that they could be resolved into two or three different and successively diminishing logarithmic rates of decline, depending on

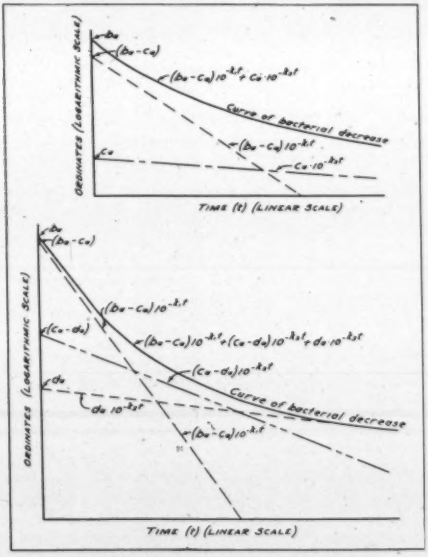

FIG. 5.—Diagrammatic illustration of derivation of equations (1) and (2), showing graphical determination of constants.

the source of the curve and the mean temperature. The curve itself thus consisted of the sum of the ordinates of two or three logarithmic curves, each conceivably representing the death rate of a separate group of bacteria following a distinctly logarithmic rate of decline.

The manner in which a composite curve of this type was built up, or resolved into its logarithmic components, is illustrated in Figure 5, which has been drawn for two different cases, one combining two, and the other three, logarithmic rates of decline. In these hypothetical graphs, (y) denotes the numbers of bacteria remaining after various

times (t), beyond the point of maximum numbers, and the other terms, constants as indicated. In the upper section of the chart, the (y) curve is composed of the sums of the ordinates of the two logarithmic functions, $(b_a - c_a) \cdot 10^{-k_1 t}$ and $c_a \cdot 10^{-K_2 t}$, which are shown as straight lines because the ordinate scale assumed is logarithmic. The lower curve is built up similarly, but from three rather than two logarithmic ordinates.

With the common logarithmic base (10), the equations thus developed may be written:

$$y = (b_a - c_a)10^{-k_1 t} + c_a \cdot 10^{-k_2 t} \quad (1)$$

$$y = (b_a - c_a)10^{-k_1 t} + (c_a - d_a)10^{-k_2 t} + d_a \cdot 10^{-k_3 t} \quad (2)$$

The progressive decline of bacterial numbers observed in the Ohio River stretch below the point of their maximum concentration was found to proceed in accordance with an equation identical with (1) except that it was expressed in the following form in the report of the Ohio River survey:* $y = a(10^{-bx}) + c(10^{-dx})$. In this connection it was pointed out† that "if the assumption of a diminishing rate of bacterial decrease is correct, then the curve of decrease might be supposed to be a composite, not of two, but of a great number of lines of successively diminishing slope; so that the general equation of the type adopted would be of the form:

$$y = ae^{-bx} + ce^{-dx} \cdots + me^{-nx}." \quad (3)$$

It was further noted that this series form of equation, though it can be fitted very closely to the downward limbs of the river curves (and also, as above noted, to those of the stored sample curves), probably is not in fundamental form, as a number of variables not specifically written into the equation may modify the trend of bacterial decrease. Among these are the actual density of bacteria and, under natural conditions, variations in depth, inflow, sedimentation and other physical conditions, which have been previously noted.

To test the rationality of this form of bacterial death rate equation, it has been suggested by Professor E. B. Phelps‡ that if we assume a very large number of groups of bacteria having a specific death rate varying from (K) to zero in direct proportion to the sizes of the various groups, a simple equation connecting the residual numbers of bacteria and the time can be derived as follows.

Consider time (t) a constant and a group of bacteria (G) made up of a large number of subgroups (g), each having a differential death rate $d(g_a e^{-Kt})$, (K) being variable and directly proportional to the size of the

* *Public Health Bulletin* **143**, 304.
† *Public Health Bulletin* **143**, 320.
‡ *Personal communication.*

subgroup. In the middle of the entire group, (g) would have a value of $k = \frac{1}{2} K$, so that (K) is linear with respect to (g).

Let $K = ag$; whence

$$g_a = \int_0^{g_a} dg$$

and

$$G = \int_0^{g_a} dg \cdot e^{-agt} = \frac{1 - e^{-ag_a t}}{at} = g_a \cdot \frac{1 - e^{-Kt}}{Kt}$$

Transposing

$$\frac{G}{g_a} = \frac{1 - e^{-Kt}}{Kt} = \frac{1 - 10^{-K't}}{2.3K't} \tag{4}$$

In Figure 6 are shown two comparative plots of curves based on the stored sample data for Ohio River Station 475, expressed in terms of

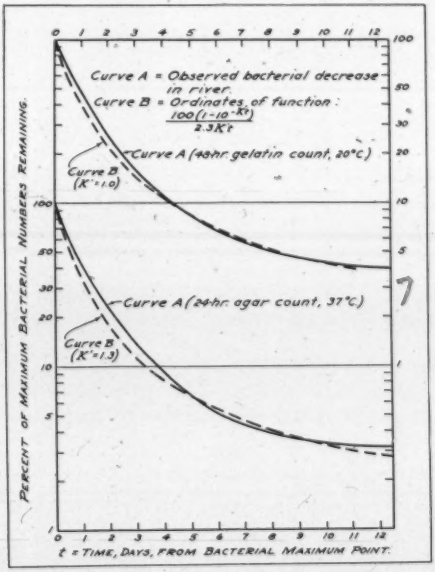
Curve A = Observed bacterial decrease in river.
Curve B = Ordinates of function: 100(1-10^-K't) / 2.3K't
Curve A (48 hr. gelatin count, 20°C.)
Curve B (K'=1.0)
Curve A (24 hr. agar count, 37°C.)
Curve B (K'=1.3)
PERCENT OF MAXIMUM BACTERIAL NUMBERS REMAINING.
t = TIME, DAYS, FROM BACTERIAL MAXIMUM POINT.

FIG. 6.—Comparison between observed curve of bacterial decrease in Ohio River below Cincinnati and corresponding curve obtained from equation (4), with assumed values of constant (K').

the 20° C. and 37° C. plate counts, together with plots of curves based on Equation (4), using the common base (10) and assuming (K') as being equal to 1.0 and 1.3, respectively. The approximate agreement between the actual and calculated curves indicates that Equation (4), though not sufficiently flexible to fit the observed data as well as Equations (1) and (2), yields curves of the same general form and serves to confirm the rationality of the latter.

In the foregoing connection, it may be further noted that recently Setter,* using Chick's formula of bacterial death rate derived from her disinfection experiments, has reported good agreement between curves of decline thus developed and actual observations in three polluted natural streams. A remarkable feature of Setter's results is the closeness with which Chick's formula, with a slight modification of its single constant, fitted these observations. As originally developed by Chick, the bacterial death rate under disinfection was expressed as $-\frac{dn}{dt} = Kn^{1.5}$, in which ($n$) denoted the variable numbers of bacteria and (t) the time. Setter found that, by changing the value of the exponent from 1.5 to 1.4, a very fair agreement with the river observations resulted.

In the present study, a much closer fitting of the stored sample and Ohio River curves of decline was obtained with the series type of equation given in (1) and (2) than with either the more simple Chick formula or the modification suggested by Phelps, doubtless because of the greater flexibility of the series equation, with its greater number of constants. The general agreement shown, however, between Chick's disinfection curves and those representing bacterial decline under the influence of natural purification is highly significant of the fundamental similarity which appears to exist between these two different phenomena.

Formulation of Complete Curves.—In connection with the report of the Ohio River survey, Dr. Frost and the writer, with the assistance of Dr. L. J. Reed, undertook to formulate a general equation for the curves of bacterial change observed in the Ohio River below Cincinnati, including the slightly crested portions defined by the initial increase in bacterial numbers observed within a few hours below the sewer outlets (see Figure 2). The form of equation developed, which was suggested by Dr. Reed, was as follows:

$$y = \frac{b}{1 + (cx + d)e^{ax}}$$

* L. R. Setter: A Comparison of the Pollution and Natural Purification of the Connecticut and Delaware Rivers and Brandywine Creek. *New Jersey Agric. Expt. Sta. Bull.* 545, 35–37, June, 1932.

in which (y) denotes the numbers of bacteria after time (x) from the start and (a), (b), (c) and (d) represent empirical constants.*

Although equations of this type were found to fit the river data fairly well, they were not sufficiently flexible to conform to the stored sample curves. Moreover, the actual process of fitting curves of this type was laborious and time-consuming, as it permitted no graphical approximations. These considerations led to an effort to formulate the curves along the same empirical lines as had been followed in deriving equations (1) and (2), the constants for which could be determined very readily and with a fair degree of accuracy by a simple graphical method such as that illustrated in Figure 5. Advantage could be taken of the fact that beyond the maximum points the curves defined by the new equations would coincide with those yielded by Equations (1) and (2); hence the new equations would include terms identical with those of (1) and (2) and, in addition, a new term defining the growth phase of the curve prior to reaching the maximum point.

From a study of a number of representative curves obtained from the stored sample tests, it was found that if plots of Equations (1) and (2) were projected backward from their previous time origin at the maximum point to a new origin located at the true starting point of the curve, the arithmetical differences between the ordinates of such an extended curve and the corresponding ordinates of the actual curve at the left of the maximum point were definitely related to a function of time, as measured from the initial point of the curve. In Figure 7, illustrating the method followed in deriving the full equations of the crested curves, the extension of the curve of bacterial decline, as given by Equation (1), back to the true origin of the curve is shown by Line A, which is made up of the sums of the ordinates of the two logarithmic functions represented by Lines B and C, as in Figure 5. The shaded area represents that which is cut off by the ordinate differences between Line A and the actual bacterial curve, which starts with the ordinate (y_a), which in the plot has been taken as unity. At the origin of the curve this difference is equal to ($b_a - y_a$) and it diminishes with time (t) according to the function ($b_a - y_a$) 10^{-kt^n}, which has been found by trial to hold for all of the stored sample and river bacterial curves to which the formulation has been applied. A plot of this function, which is represented by the line D, shows that although it never reaches mathematical zero, it practically disappears at a point near the maximum crest of the curve, where Line A merges with the actual curve and thereafter shapes its phase of decline.

* For a complete description of this equation and of fitting it empirically to the river data, see *Public Health Bulletin* 143, 290–298.

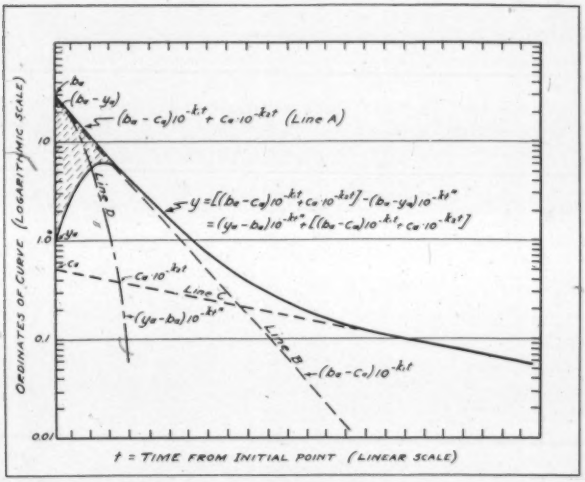
ORDINATES OF CURVE (LOGARITHMIC SCALE)
10
1.0
0.1
0.01
b_a
$(b_a - y_a)$
$= (b_a - c_a)10^{-k_1 t} + c_a \cdot 10^{-k_2 t}$ (Line A)
$y = [(b_a - c_a)10^{-k_1 t} + c_a 10^{-k_2 t}] - (b_a - y_a)10^{-k_1 t^n}$
$= (y_a - b_a)10^{-k_1 t^n} + [(b_a - c_a)10^{-k_1 t} + c_a \cdot 10^{-k_2 t}]$
Line B
y_a
c_a
$c_a 10^{-k_2 t}$
Line C
$-(y_a - b_a)10^{-k_1 t^n}$
Line D
$-(b_a - c_a)10^{-k_1 t}$
t = TIME FROM INITIAL POINT (LINEAR SCALE)

FIG. 7.—Diagrammatic illustration of derivation of equation (5), showing graphical determination of constants.

The full development of the two equations fitting the actual data, one of which is given in connection with Figure 7, may be stated in general form as follows:

$$y = [(b_a - c_a)10^{-k_1 t} + c_a \cdot 10^{-k_2 t}] - (b_a - y_a)10^{-k t^n}$$
$$= (y_a - b_a)10^{-k t^n} + [(b_a - c_a)10^{-k_1 t} + c_a \cdot 10^{-k_2 t}] \quad (5)$$

$$y = [(b_a - c_a)10^{-k_1 t} + (c_a - d_a)10^{-k_2 t} + d_a \cdot 10^{-k_3 t}] - (b_a - y_a)10^{-k t^n}$$
$$= (y_a - b_a)10^{-k t^n} + [(b_a - c_a)10^{-k_1 t} + (c_a - d_a)10^{-k_2 t} + d_a \cdot 10^{-k_3 t}] \quad (6)$$

In these equations, (y) denotes the numbers of bacteria after times (t), (y_a) their initial numbers, and the other constants except (n) the same as in equations (1) and (2), which it will be noted are identical with the terms within the brackets [ ] in equations (5) and (6). The term (n) is a constant, the value of which determines the sharpness of crest of the bacterial curve.

The actual fitting of Equations (5) and (6) to the observed data can be done graphically, as in the case of the downward limbs of the curves illustrated in Figure 5. At the left of the maximum point of the curve, the differences $(y_a - b_a)$ are scaled from a plot of the curve. If we de-

note these differences by the symbol (y_d), then we have:

$$\frac{y_d}{y_a - b_a} = 10^{-kt^n}$$

whence

$$\log \frac{y_d}{y_a - b_a} = -kt^n$$

and thence

$$\log \left(\log \frac{y_a}{y_a - b_a} \right) = n \log t - \log k$$

By plotting values of $\log \left(\log \frac{y_a}{y_a - b_a} \right)$ against corresponding values of $(\log t)$, a straight line is obtained, the slope of which fixes the value of (n) and the intercept on the zero time axis the value of $(\log k)$.

Numerical Values of Constants.—From a number of plots of the stored sample and river curves, similar to those shown in Figure 1 but extended for longer time periods, values of the constants in Equations (5) and (6) have been derived, following the graphical method above described. In order to illustrate the range and general trend of these constants, numerical values obtained from plots of the data given in Tables I and II have been summarized in Table III, omitting those based on the stored sample curves at Ohio River Station 598. All of the curves represented in Table III are of the type conforming to Equation (5); hence their values may be directly compared.

TABLE III.—*Numerical Values of Constants in Equations (5) and (6) for Curves Plotted from Data Given in Tables I and II*

	k	k_1	k_2	n	$y_a - b_a$	$b_a - c_a$	c_a
(1) Stored Sample Observation, 20° C. Counts, Yearly Averages, Ohio River Station 475 (Table I)							
Storage Temp.:							
10° C.	0.36	0.30	0.015	1.11	48.5	49.0	0.015
20° C.	1.46	0.35	0.017	1.09	7.4	8.1	0.017
37° C.	2.16	0.80	0.060	1.25	8.0	8.6	0.060
(2) Ohio River Observations, Summer Averages (Table II)							
20° C. Counts	0.34	0.36	0.063	1.46	3.30	4.32	0.025
37° C. Counts	0.38	0.36	0.076	1.78	3.67	4.67	0.031
B. Coli Index	1.70	0.36	0.083	1.10	1.83	2.74	0.026

In the three series of constants derived from stored sample data for Ohio River Station 475, the effect of increased temperature of storage is apparent in the trend of the several constants. Thus it is noted that the value of (k) increases throughout the entire temperature range and those of (k_1) and (k_2), sharply between 20° and 37° C.

Comparison of the constants derived from the stored sample curves with those obtained from the direct observations in the Ohio River below Cincinnati shows that, beyond the maximum point of bacterial density, the primary rate of decline, which is given by the constant (k_1), was practically the same in the river as in the stored samples at 20° C. The secondary rate, however, which is indicated by the value of (k_2), was markedly higher in the river than in the stored samples, reflecting the divergence between the two rates shown in Figure 2 under summer conditions, with prolonged time periods beyond the maximum point of the curves. It also will be noted that the values of the constants for the curves defined by the three different groups of bacteria in the river observations were fairly consistent among themselves, except for slight deviations in those based on the *B. coli* data.

In connection with Table III, it may be of interest to note the effect of correcting the summer curve of bacterial decline in the river for turbidity change resulting from sedimentation, as done in connection with Figure 4. In the following tabulation, values of the constants (k_1), (k_2), $(b_a - c_a)$ and (c_a) in Equation (1) are given for Curves *A*, *C* and *D* in Figure 4, the first representing the uncorrected rate of decline in the river, the second the corrected rate, and the third the corresponding rate in the stored samples from Station 475 at 20° C.:

	(k_1)	(k_2)	$(b_a - c_a)$	(c_a)
Curve *A*	0.38	0.099	0.97	0.028
Curve *C*	0.33	0.062	0.93	0.070
Curve *D*	0.32	0.036	0.92	0.078

The effect of correcting Curve *A* for sedimentation is thus shown to bring all of the constants into line with those of the stored sample Curve *D*, except for (k_2), which, though diminished, remains somewhat higher than for Curve *D*. This variance may be interpreted as indicating that under conditions of extremely low water, such as would coincide with the more prolonged times of flow represented by the portion of Curve *C* extending beyond 6 days, observed reductions in the turbidity of the river, which are the basis of Curve *B*, probably are somewhat less than in direct proportion to corresponding reductions in

bacterial content resulting from sedimentation. With these extremely low stages of the river, its turbidity is greatly diminished and under these circumstances is not so closely correlated to its suspended matter content as it is under higher stage conditions when a larger proportion of the total suspended matter present consists of measurable turbidity. As the effects of sedimentation on the bacterial population of a stream are probably reflected more nearly by progressive changes in total suspended matter than by those in measurable turbidity, any condition which tends to upset the normal proportionality existing between these two elements doubtless also disturbs the relation between measurable turbidity and bacterial changes. In some streams, where little correlation exists between turbidity and suspended matter, a correction such as made in connection with Figure 4 would hardly be valid, except as a very rough approximation.

General Significance of Empirical Equations.—The general form of crested curve defined by equations (5) and (6) has a number of parallels in microbiology and a particularly significant one in the field of physical phenomena, when considered in connection with the observed data. In microbiology, a close analogy exists in the time-curves traced by the activity of organisms responsible for various fermentations; thus Carlson * notes a similar curve for the activity of yeast cells in the fermentation of wort. In uncontrolled fermentations, curves of this type apparently result from the accumulation of toxic products, which cause a reversal of the initial growth phase into one of decline. The normality of this general type of bacterial curve is indicated by Buchanan and Fulmer,† who divide the complete cycle of growth and decline into seven distinct phases, each merging into another.

It can be shown, from simple assumptions, that an elementary form of this curve may be derived from a differential equation expressing the net rate of change in the numbers of an organism as the difference between a multiplication rate and a death rate, the former proportional to a limiting growth function and the latter, to a function of the numbers of the organism present at any given time. To illustrate, let $\left(\frac{dy_1}{dt}\right)$ denote the rate of multiplication, $\left(\frac{dy_2}{dt}\right)$ the death rate, $\left(\frac{dy}{dt}\right)$ the net rate of change in the number of organisms (y) present at any time (t), and (F) the limiting growth function. Then we may write:

$$\frac{dy}{dt} = \frac{dy_1}{dt} - \frac{dy_2}{dt} = k_1 F - k_2 y$$

* Carlson, *Biochem. Zeit.*, 57, 313–334.

† F. E. Buchanan and E. R. Fulmer: Physiology and Biochemistry of Bacteria. Vol. I, pp. 16–18.

If we assume that (F) diminishes at a logarithmic rate, the integrated form of this equation will be

$$y = \frac{k_1 F_a}{k_2 - k_1} \cdot e^{-k_1 t} - \left(\frac{k_1 F_a}{k_2 - k_1} - y_a \right) e^{-k_2 t} \qquad (7)$$

in which (F_a) denotes the initial value of (F), (y_a) the initial number of organisms, and (k_1) and (k_2) constants.

To simplify equation (7), let the two constant terms be replaced by (c_1) and (c_2); whence, we may write

$$y = c_1 e^{-k_1 t} - c_2 e^{-k_2 t} \qquad (8)$$

Equation (8) is identical with that which in physics defines the single-crested curve of an "aperiodic" or completely "damped" oscillation,* this curve being a special form of the ordinary periodic damped oscillation curve, which is wave-like in its trend. An interesting analogy exists between the "periodic" and "aperiodic" forms of the damped oscillation curve and bacterial curves obtained by Purdy and Butterfield † from their study of the inter-reactions between various strains of bacteria and of bacteria-consuming plankton, both in pure and in mixed cultures. With pure cultures, the curves traced by both organisms were of the periodic type, each curve being opposite in phase to the other. With mixed cultures, the corresponding curves were distinctly aperiodic, or single-crested, tending toward a sharper crest with the more highly mixed strains approaching those of sewage and polluted natural water. The contrast between these sharper-crested curves and the more rounded ones obtained from less heterogeneous mixtures of organisms was analogous to that shown between the general form of curve defined by equations (5) and (6) and that which is defined by equations (7) and (8).

It thus appears that the stored sample and river bacterial curves defined by equations (5) and (6) probably represent the ultimate development of a series of curves, beginning with the periodic form in pure cultures and ranging, with increasingly wider varieties of bacterial and plankton strains, through the more rounded single-crested curves, such as are defined by equations of types (7) and (8), to the sharper-crested forms, such as are given by equations (5) and (6), which are characteristic of the extremely heterogeneous flora existing in polluted natural waters.

The two features which appear to distinguish these "natural water" bacterial curves from those obtained under artificial conditions with

* See J. W. Mellor: Mathematics for Students of Chemistry and Physics. 1916 Edition, pp. 409–410.

† W. C. Purdy and C. T. Butterfield: The Effect of Plankton Animals on Bacterial Death Rates. *Am. Jour. of Pub. Health*, 8, 499–505 (July, 1918).

more restricted varieties of organisms are the marked retardation in the rate of initial increase, as compared with a logarithmic rate, beginning at an early stage of this phase, and the progressively diminishing rate of decrease beyond the maximum crest, which has been fully discussed at an earlier point in this paper. The retarding influence during the initial phase of increase, which probably is due to the resumption of predatory activities by the plankton following bacterial multiplication, is manifested in equations (5) and (6) by the appearance of the power (n) as a function of time, which has the effect of bending the curve downward as it approaches the maximum point and of bringing the maximum to a lower level than otherwise would be the case. In this connection it is of interest to note that the term, $(y_a - b_a)10^{-kt^n}$, in equations (5) and (6) is exactly analogous to the Penfold bacterial growth function, which Buchanan and Fulmer * give as Bc^{kt^n}, except that the exponent of the former is negative and that of the latter, positive. The reason for this difference of sign is that the former is a diminishing function, owing to the retarding effect of the plankton, whereas the latter is an increasing function subject to retardation only as the numbers of bacteria approach their saturation point with a particular food concentration. It can readily be shown, by differentiating these two functions, that their differential rates of change are mathematically identical, though of opposite signs. This merely signifies that the curve of initial bacterial increase observed in the stored samples of river water and sewage tends to follow the normal growth function, except as modified by the active retarding influence of plankton, which is made effective long before the numbers of bacteria reach their saturation point from starvation. It thus may be inferred that predatory plankton, rather than starvation, constitute the major factor in the bacterial changes associated with the natural purification of polluted waters.

Relation of Bacterial Curves to Oxidation Phenomena

In connection with a study of the influence of plankton on the biochemical oxidation of organic matter, it has been observed by Butterfield, Purdy and Theriault † that under experimental conditions approaching those existing in polluted natural waters, the rate of oxidation depends very largely on the rate at which the bacteria present were actively multiplying. These results suggest that under conditions of the ordinary laboratory test for biochemical oxygen demand (B.O.D.)

* *Loc. cit.*, page 31.

† C. T. Butterfield, W. C. Purdy and E. J. Theriault: Experimental Studies of Natural Purification in Polluted Waters, IV. The Influence of Plankton on the Biochemical Oxidation of Organic Matter. *Public Health Reports*, **46**, No. 8, 393–426 (Feb. 20, 1931) (Reprint No. 1451).

which are similar to those under which the stored sample tests discussed in the present paper were conducted, a relationship might exist between the normal course of oxidation and that of progressive bacterial changes in the sample, assuming the latter to be fairly represented by the stored sample data.

If the rate of oxidation of organic matter in a polluted natural water be proportional to the rate of bacterial multiplication at any time, then the total amount of organic matter oxidized up to a given time should be represented by some direct function of the total number of bacteria generated up to that time. If all of the bacteria should survive in the culture, the total number generated up to any time would be equal to the total number present at that time. If some bacteria failed to survive, the actual number generated in any interval of time should be roughly proportional to the average number present during that period and the total number generated up to a given time should be proportional to the cumulative numbers present in the water up to that time. The latter would be measured by the corresponding total area lying under the bacterial curve.

For the purpose of illustration, let us assume a bacterial curve following a simple logarithmic path of decrease. This curve would be represented by the relation $y = ce^{-kt}$, expressed in general terms. The area (Y) lying under this curve, up to any time (t) would be given by the expression

$$Y = \int_0^t y\,dt = \int_0^t ce^{-kt}\cdot dt = \frac{c}{k}(1 - e^{-kt}), \qquad (9)$$

which determines the cumulative numbers of active bacteria present up to any time.

An exact parallel can be shown to exist between these two bacterial functions, (y) and (Y), and those which define, respectively, the rate at which biochemical oxygen demand is satisfied according to the familiar logarithmic rule and the cumulative demand satisfied up to any given time. Expressed in similar terms, these may be written as

$$L = L_a\cdot e^{-Kt} \quad \text{and} \quad X = L_a(1 - e^{-Kt}) \qquad (10)$$

in which (L) denotes the B.O.D. at any time (t), (L_a) its initial B.O.D., (X) the total amount satisfied up to time (t) and (K) a specific rate constant.

It thus appears that on the basis of the above assumptions, a strictly logarithmic rate of bacterial decrease in a sample of polluted water should yield an oxygen demand curve identical with that which has been observed normally under the practical conditions of the laboratory test. Let us now examine briefly the result to which a similar mathematical

process would lead, when applied to the crested bacterial curves represented by equations (5) and (6), considering equation (5) as an example.

For convenience, let us re-write equation (5) as

$$y = -ce^{-kt^n} + c_1e^{-k_1t} + c_2e^{-k_2t} \tag{11}$$

in which the Naperian base (e) has replaced the common base (1), and (c) (c_1) and (c_2) the constants ($y_a - b_a$), ($b_a - c_a$) and (c_a) respectively. If we denote the integrated area lying under the curve as Y, we then may express this area as follows:

$$Y = \int_0^t y\,dt = \int_0^t (-ce^{-kt^n} + c_1e^{-k_1t} + c_2e^{-k_2t})dt$$
$$= \int_0^t -ce^{-kt^n}dt + \int_0^t c_1e^{-k_1t}dt + \int_0^t c_2e^{-k_2t}dt$$

The first term of this function, containing the exponent (n), cannot be integrated definitely, but as a close approximation we may take advantage of the fact that (n) does not greatly exceed unity, as is indicated in Table 3, and may be disregarded as an integration factor in view of the relatively small weight that this first term has in the numerical values obtained from the entire equation. We may then express the integral of the term in the same general form as that of the other two terms and write the definite integral of the equation as

$$Y = -\frac{c}{k}(1 - e^{-kt^n}) + \frac{c_1}{k_1}(1 - e^{-k_1t}) + \frac{c_2}{k_2}(1 - e^{-k_2t}) \tag{10}$$

and from it obtain a reasonably close approximation of the true area curve.

In Figure 8 is shown a plot of an area curve defined by equation (10) using the constants, based on the curve of bacterial changes observed in stored samples collected at Ohio River station 475, and stored at 20° C. (see Table III). For convenience, the common base (10) has been used instead of the Naperian base (e) in computing the ordinates of this curve. For comparison with this area curve, a plot is shown of the simple logarithmic function, $Y = c(1 - 10^{-0.1t})$, assuming a value of (c) equal to 27.7, the ordinate of the former curve at 20 days and a value of (k) equal to 0.1, which corresponds to that of the B.O.D. specific rate constant at 20° C. This latter curve would be followed by the cumulative B.O.D. satisfied up to various times (t) assuming the ordinary logarithmic rate of satisfaction and a 20-day B.O.D. of 27.7 units.

Although these two curves follow each other closely after 5 days, the integrated bacterial curve gives considerably higher ordinates than the B.O.D. curve up to this time, indicating an apparently greater cumu-

lative number of bacteria present than would be accounted for in terms of the expected total amount of B.O.D. satisfied. This result would suggest the possibility that during the earlier stages, the rate of effective oxidation at any time may not be strictly proportional to the rate of bacterial multiplication at that time. This possibility is consistent with the evidence found in the relative trends of the two curves of Figure 8.

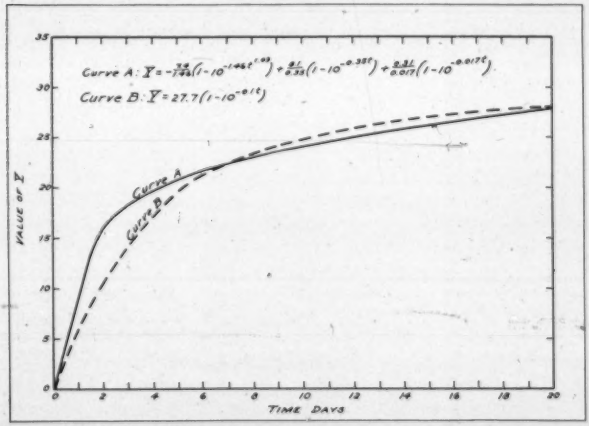

FIG. 8.—Comparison between curve obtained from equation (10), with constants giving cumulative numbers of bacteria present in samples of Ohio River water stored at 20° C. up to various times, and normal logarithmic curve of cumulative amounts of B.O.D. satisfied at 20° C. up to corresponding times, assuming the same ordinate for both curves at 20 days from start.

of a distinct lag between successive increments of bacterial population, as shown by curve *A*, and corresponding increases in the amounts of oxidized material formed, which are measured by curve *B*. Thus, if the ordinates of curve *A*, beginning with the first day or so after the start, were shifted to the right on the time scale by a distance corresponding to somewhere between 1 and 2 days of time, the two curves would tend to follow each other much more closely up to about 5 days and not to diverge materially after that time.

A lag effect of this kind could be produced, conceivably, if the process of oxidation were actually accomplished through the medium of bacterial enzymes or some other agent resulting from bacterial activity. Under these circumstances, a certain interval presumably would elapse between

the time of a given degree of bacterial activity and the time at which it would become effective in terms of organic matter oxidized. In this connection it is of interest to note the recent suggestion by Wooldbridge and Standfast * that bacterial enzymes probably are important factors in biochemical purification of sewage.

Although the foregoing questions will require further study before they can be answered more definitely, the tentative conclusion appears justified from the evidence of this study that the oxidation of organic matter in polluted water containing its natural biological elements is definitely influenced, either directly or indirectly as above suggested by the degree of bacterial activity in the water, which in turn is related to the numbers of bacteria present in the water at any time. As noted by Butterfield, Purdy and Theriault, this activity may be maintained by virtually any agency which tends to keep the bacterial population below its point of saturation with a given available food supply. Under natural conditions found in polluted streams and lakes, it seems likely that the major factor thus involved is the preying of bacteria-consuming plankton on the bacteria, though dilution and sedimentation also may play a part, in so far as the supernatant body of water is concerned. In bottom sludge blankets, where they exist, biological conditions may be greatly intensified and other factors, such as the accumulation of oxidized products, may exert some effect. From the close parallelism found in this study between the trend of bacterial decrease in the stored samples of Ohio River water and in the river itself, when due allowance has been made in the latter case for the effect of sedimentation, it seems reasonable to conclude that whatever oxidation changes may be observed in a sample of polluted river water under conditions of the ordinary laboratory test for B.O.D. would be expected to follow about the same course in the supernatant portion of the river proper, though it should be emphasized in this connection that the true rate of oxidation in the stream may be masked by progressive changes in the oxygen demand of the overlying water due to the modifying influence of sedimentation, scour and inflow and to those of the intensive oxidation changes which may occur in the sludge blanket lining the channel.

Summary and Conclusions

1. A comparative mathematical study was undertaken of curves defined by progressive changes in bacterial content observed in the Ohio River below Cincinnati and in samples of river water and sewage when stored in the laboratory for periods of 40 days or more at three different temperatures, 10°, 20° and 37° C.

* W. R. Wooldbridge and A. F. B. Standfast: Bacterial Enzymes in the Purification of Sewage. *Nature*, 130, 66–77; This Journal, 5, 553 (May, 1933).

2. The greater rates of bacterial decline observed in the river under summer low-water conditions, as compared with rates observed in stored samples of the river water at about the same temperature as that of the river, appear to have been due very largely to the effect of progressive changes in suspended matter resulting from sedimentation. When corrected for this effect, these rates are shown to have been very nearly the same, as they were likewise in the river under winter high-water conditions, when sedimentation was not a factor and changes in suspended matter were unimportant. From these indications it is concluded that the rates of bacterial decline observed in the stored samples of river water and likewise in the river itself, when the latter are corrected for sedimentation effect, probably represent a fair approximation to the true bacterial death rates at a particular temperature and under conditions of natural purification in the stream.

3. To express the trend of the bacterial curves derived from the stored sample tests and the river observations, two empirical equations of the same general type have been developed from the data. These equations have been found to fit the data more closely than those of any other type studied. Constants have been derived for several typical bacterial curves. These constants have been shown to bear a definite relation to temperature and also to be influenced by the relative density and age of pollution.

4. From a comparative study of the empirical equations derived for the bacterial curves with other equations developed from simple assumptions, it is indicated that the former are shaped primarily by the influence of an active suppressive force which probably represents the effect of bacteria-consuming plankton. The results of this phase of the study also suggest that the departure noted between the observed bacterial curves and those developed from simple assumptions are probably due to the highly mixed strains of bacteria and plankton present under the natural conditions which actuate the former.

5. A comparison of the empirical equation developed from the observed bacterial curves with those derived by other observers for similar phenomena has shown an analogy between the multiplication term in the former and Penfold's bacterial growth function; likewise between the diminishing rate of bacterial decline indicated by the former and that which has been noted by Chick and Scharff from their respective studies of death rates of bacteria when exposed to disinfectants and to the ultraviolet ray.

6. A further analysis of the empirical equations developed from the bacterial curves has indicated that under conditions of the laboratory test for biochemical oxygen demand, which correspond closely to those of the stored sample tests, the total amount of B.O.D satisfied up to any

time, which is ordinarily given by the simple logarithmic integral function, $Y = c(1 - e^{-kt})$, appears to bear a definite relation to the cumulative numbers of bacteria present in the sample up to that time, or to the total numbers of bacteria generated up to that time. From a comparative plot of the integral of the observed bacterial curves, which measures the cumulative numbers of bacteria present up to a given time, with that of the simple logarithmic integral function of B.O.D. satisfied up to the same time, a lag effect is shown between the rate of bacterial growth and the rate of formation of oxidized material. It is suggested that this lag effect may be due to the formation of intermediate bacterial enzymes, which in acting as carriers of the oxidation reaction cause a certain delay in completion of the reaction. As the trend of the major portions of the river curves is similar to that of the stored sample curves, it may be inferred that the mechanism and rates of satisfaction of B.O.D. under natural stream conditions are about the same, in the supernatant stream water, as under conditions of the ordinary laboratory test.

HYDROGEN-ION CONCENTRATION AND BICARBONATE EQUILIBRIUM IN DIGESTING SLUDGE

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The determination of the hydrogen-ion concentration of digesting sewage sludge has grown in importance in the empirical correlation of certain digestion phenomena. Its practical use had been to designate conditions concurrent with favorable or undesirable digestion. The authors of the present paper are not aware of published studies in this field which have given quantitative consideration to the mechanism by which the pH attains its value. This paper is a discussion of some phases of this mechanism.

Theory

In the course of sludge digestion, various alkaline and acid compounds go into solution. Of the alkaline substances NH_3, resulting from the decomposition of protein, is most important. Significant amounts of lime and magnesia are liquefied through the decomposition of hard soaps. The sodium in solution increases but little. Of the acid compounds the principal variation is found in the organic acids, especially acetic. The organic acids are formed in large amounts in the early stages of digestion and eventually are largely destroyed. Changes in the fixed acids—chloride, phosphate and sulphate—have a minor effect on the total of acid constituents. Except in extremely acid sludge, the alkaline substances are in excess of the fixed and organic acid substances. Carbon dioxide (CO_2) is also formed, and being an acid substance neutralizes the excess alkalinity by the formation of bicarbonate ion. Only a negligible amount of secondary carbonate ion is formed at the pH values of digesting sludge. There is also free CO_2 in solution, in amount depending upon the partial pressure of CO_2 in the gas with which the solution is in equilibrium.

In any solution containing bicarbonate and in equilibrium with a gas phase containing CO_2, the pH should satisfy a well-established chemical equilibrium expression which may be conveniently written

$$pH = pK - \log \frac{pCO_2 \times \alpha CO_2}{760 \times 22.4} + \log (HCO_3^-)$$

pK is a constant dependent upon the temperature, pCO_2 is the equilibrium partial pressure of CO_2 in mm. of Hg and αCO_2 the conventional solubility coefficient for CO_2, and (HCO_3^-) is the activity of the bicarbonate ion in mols per liter. This last term is slightly lower than the

concentration of bicarbonate, due to the effect of other ions in solution. Hastings and Sendroy (1) took into account the effect of the other ions on the basis of the Debye-Hückel theory and introduced a correction term, whereby the equation may be written

$$pH = pK - \log \frac{pCO_2 \times \alpha CO_2}{760 \times 22.4} + \log [HCO_3^-] - 0.5\sqrt{\mu}$$

in which $[HCO_3^-]$ is the bicarbonate concentration and μ is the ionic strength, or one-half of the summation of the concentration of each ion species multiplied by the square of its valence.

Careful determinations of the constant in this equation have been made by Warberg (2), by Hastings and Sendroy (1), by Stadie and Hawes (3), and by Wilson, Orcutt and Robertson (4), with their results in excellent agreement. The conditions under which these basic experiments were conducted covered a temperature range from 17° C. to 38° C., ionic strengths from 0.001 to 0.18 in simple and in blood solutions, pressures of CO_2 from 0.5 to about 600 mm. of mercury, and pH values from 5.60 to 8.00. The best value of the constant at 25° C. is 6.395. For the purpose at hand it is convenient to express the partial pressure of CO_2 in atmospheres and the concentration of bicarbonate in parts per million of CO_2. The equation then becomes

$$pH = 3.22 - \log pCO_2 + \log [HCO_3^-] - 0.5\sqrt{\mu}$$

Experiments

A series of experiments were made by the authors to determine if the pH values of the liquors of digesting sludges, as ordinarily determined with indicators, correspond to the above equation. The tests were made on samples of sludges from the four-stage digestion tanks, described elsewhere (5), of the Los Angeles County Sanitation Districts. Samples of the sludges were allowed to stand in the laboratory until a layer of fairly clear liquor could be pipetted off, and where necessary this was further filtered. In order to test the theory over a wider range of pH values than those occurring naturally in the tanks, some of the samples were adjusted to higher alkalinities by the addition of ammonia or sodium bicarbonate, or to lower alkalinity by boiling out the ammonia occurring naturally, by adding acetic acid, or by moderate dilution. The samples of liquor were then shaken with gas piped to the laboratory from the digestion tanks. The CO_2 content of this gas was normally between 30 and 32 per cent. In cases where the percentage of CO_2 was outside these limits, corrections were applied to the results. After sufficient time had been allowed to attain equilibrium, which was reached fairly rapidly in the more acid samples but which required at least two hours

in the most alkaline samples, portions were tested with indicators in the usual manner. The air in the test tube was displaced with sludge gas to prevent loss of CO_2 from the liquor when it was mixed with the indicator.

The indicators used were chlorphenol red, bromthymol blue, and phenol red. Comparisons were made with the colors obtained in standard phosphate buffers (M/15) made up to intervals of 0.1 pH unit, and also with LaMotte commercial ampoules. No significant differences were found between the buffers and the LaMotte standards. In the case of the red indicators no difficulty was experienced in the usual procedure of using a 10 ml. sample plus 0.5 ml. of indicator solution in a $\frac{5}{8}$-in. test tube, but in order to counteract absorption of the dye in the case of bromthymol blue, a smaller test tube and a more concentrated indicator solution were used, as recommended by McCrumb (6). The same sample was tested with two indicators where the ranges overlapped, and the results averaged. In these cases the bromthymol blue frequently gave a somewhat lower reading than the red indicators, the discrepancy averaging 0.06 pH unit.

The concentration of bicarbonate was determined by adding an excess of acid, boiling out the CO_2, and titrating back to the original pH with base. Details of this procedure are set forth further on. The tests were made at an average temperature of 25° C. (77° F.). Use of a thermostat was not necessary because the temperature effect is small, but variations of more than 3° C. from the average were avoided.

In order to compare the results of these tests with the equation, an estimate must be made of the ionic strength of the sludge liquor. Analyses of the sludge liquor made at this plant indicate an ionic strength varying from about 0.06 for seeded sludge four or five days old, to 0.10 at the end of the process, with an average of about 0.09 during the greater part of the digestion period. The error will be negligible if 0.09 is used throughout the range.

In Figure 1 the points show the experimental results and the curve is drawn according to the equation

$$pH = 3.22 - \log pCO_2 + \log [HCO_3^-] - 0.5\sqrt{\mu}$$

with pCO_2 set equal to 0.31 and μ equal to 0.09. The agreement is satisfactory. The points in the middle range were determined with bromthymol blue. The fact that these are relatively lower is probably related to the effect noted when the same sample of liquor was tested with bromthymol blue and one of the red indicators, with the blue indicator usually giving lower values. Such deviations as do appear are not surprising in view of the probability of errors from incorrect judgment of the colors, from failure to establish equilibrium, from specific

salt effect not accounted for by the Debye-Hückel theory, from uncertainty as to the ionic strength of the solutions, and from the effect of proteins on the indicators.

The data of Figure 1 were obtained by bringing the solution to equilibrium with a gas of a known percentage of CO_2. The question now arises as to whether the liquor in a separate digestion tank can be

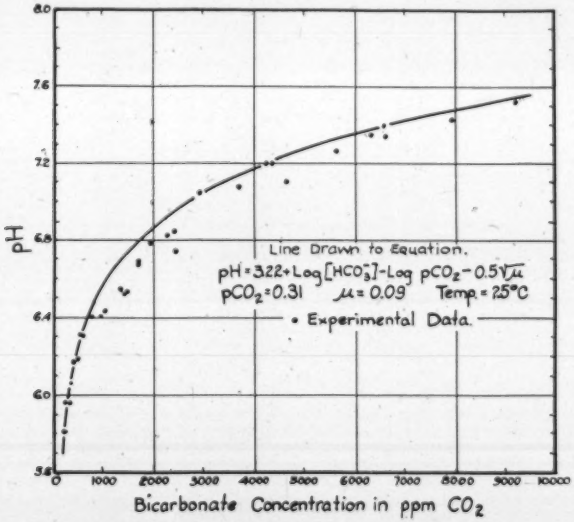

FIG. 1.—Relation Between pH and Bicarbonate Concentration.

considered to be in equilibrium with the gas which it is evolving. There must be some supersaturation. Fortunately this is not as serious as it would be if only CO_2 were being evolved. Inasmuch as methane is much less soluble than CO_2 and is produced in large quantity, it will force a continual production of bubbles which will help to gas out the CO_2.

In order to determine whether or not supersaturation is an important factor, bottles of digesting sludge were allowed to stand several hours in the laboratory. A clear layer of liquor would separate, with sludge floating above it. The floating sludge was thought to be adequate protection against undue loss of CO_2 by the stratified liquid. Samples of the liquors were pipetted off and the pH values determined with indicators. The samples were then bubbled with sludge gas and the pH

values again determined. If the samples were supersaturated this bubbling should serve to remove any excess CO_2 and allow a rise in the pH. The CO_2 content of the gas coming from the sludge was considered to be the same as that of the gas of the digestion tank from which the sample was taken. If this differed appreciably from the laboratory supply, corrections were applied. With this taken into account it was found frequently that the pH after bubbling, instead of being higher, compared to the original value, was often lower by as much as 0.18 unit, indicating that the CO_2 concentration was below the equilibrium value in spite of the methods used to avoid loss. This was the case in 7 out of 10 tests. In one case there was no change, while in the remaining two cases there appeared to be increases of 0.03 pH unit. This difference is about at the limit of experimental error of the method. In any case it seems safe to say that supersaturation was not an important factor under the conditions described.

A more serious difficulty is encountered when dealing with sludge from the bottom of a deep tank. In this case the partial pressure of the CO_2 is increased in proportion as the total pressure is increased by the head of water. If a sample from the bottom of the tank is brought to the surface it will necessarily be supersaturated. Gas will be evolved as the pressure is reduced. Since CO_2 is more soluble than CH_4, the absolute supersaturation of CO_2 will be much greater than that of CH_4, and the bubbles which form will have an abnormally high content of CO_2. It is to be expected that when the sample reaches the surface it will have a pH somewhere between that which it had at the bottom and that which it would have if it were at equilibrium at the surface.

Samples of sludge were taken from the digestion tanks at a depth of 12 feet. According to theory the pH should be 0.13 unit lower, from the effect of this depth, than at the surface. Under favorable conditions these samples yielded enough clear liquor to allow a pH determination within 15 minutes after sampling; otherwise they were not used. After the initial pH determination the samples were bubbled with sludge gas. Corrections were made for differences in CO_2 percentages between the gas from the tank sampled and the laboratory supply. Four tests were made, showing increases of pH, after correction, of 0.01, 0.05, 0.04, and 0.03. There is, of course, an uncertainty of at least 0.03 in these figures, but they do give some evidence of a small effect in the expected direction.

Discussion

It must be emphasized that the bicarbonate-carbon-dioxide equilibrium expression is very general. In accurate experiments with the pH determined potentiometrically the equation was validated over a rather wide range of conditions by Warberg, *et al.* The results pre-

sented herein have shown the substantial validity of the expression for the colorimetric pH of the sludge liquor investigated, with 31 per cent CO_2 and at about 25° C. It seems reasonable to suppose that similar agreement would be found at other temperatures and at other percentages of CO_2, and furthermore, that no sludge liquor from whatever source would show a picture substantially different as long as it could be assumed to be in equilibrium with its gas.

If one knows the bicarbonate concentration of a digesting sludge, and makes even an approximate estimate of the composition of the gas, then the equation provides a good means for calculating the pH. *It is fully as valid as the colorimetric method and probably more accurate to consider as "actual pH" the value obtained in this way than that obtained by use of the colorimetric method.* This statement does not depend upon the experimental evidence presented in this paper. The bicarbonate-carbon-dioxide equilibrium is just as truly a pH indicator as are the dyes, and is even less influenced by the sort of disturbing factors which introduce errors into the colorimetric pH. Figure 1 may be considered simply as a comparison of pH determinations by four different equilibria, three being reactions of certain dyes which are called indicators, and the other being the equilibrium between carbon dioxide and its ion products. Only the potentiometric pH, which is the ultimate standard of reference, has greater validity, but it may be no more accurate if insufficient care is used to avoid loss of CO_2 from the sample. The fact that the liquor in the tank may not be exactly in equilibrium with gas of the composition found to be coming from the tank is offset by the fact that the amount of CO_2 in solution in the sample in the test tube is not likely to be the same as it was in the tank. This is especially true if deep samples are taken, for in this case it is impossible to avoid loss of some CO_2 without the use of very elaborate apparatus.

It is interesting to estimate the maximum value which the pH may be expected to attain in the last stages of digestion. Taking an extreme case, suppose that a raw sludge at a concentration of 8 per cent solids, containing 4 per cent of nitrogen (dry basis), is permitted to digest. Further assume that two-thirds of the nitrogen is digested to ammonia. The resulting concentration of NH_3 is 2133 p.p.m. as nitrogen, which would require 6700 p.p.m. of bicarbonate as CO_2 to neutralize it. In the experimental work leading up to this study it has been found that in the later stages of digestion the ammonia is roughly equivalent to 75 per cent of the bicarbonate. Assuming a similar ratio in the hypothetical case, 8950 p.p.m. of bicarbonate CO_2 would be expected.

In order to estimate the pH of such a sludge, a CO_2 content for the gas must be assumed. From those reported analyses which appear reliable it seems probable that the gas bubbles originating in the sludge

do not often contain less than 25 per cent CO_2. This assumption is conservatively in agreement with the theoretical and experimental data presented by Buswell and Boruff (7). Forty analyses of gas from the digestors of the Los Angeles County Sanitation Districts show a minimum of 25.5 per cent CO_2.

Assuming the bicarbonate as 8950 p.p.m. CO_2 and the CO_2 content of the gas at 25 per cent, the calculated value of the pH is 7.65 for the final stages of digestion at 30° C. It is not likely that the combination of conditions necessary for this high value is often realized. The frequency with which values of 7.6 and higher are reported for digesting sludge suggests that the observers have not always used sufficient care to avoid loss of CO_2 from the samples in spite of emphasis of this point from time to time in the literature. For example, filtration is often resorted to in order to get clear liquor for the pH determination, but this method is almost sure to give erroneous results.

It is probable that pH values of digestion tanks are often lower than commonly supposed, and that the value generally assumed to be the lower limit for satisfactory digestion has been placed too high. Digestion has sometimes been found to be progressing vigorously and in a satisfactory manner in the first stage of the digestors of the Los Angeles County Sanitation Districts when the pH was 6.5 at the surface with a calculated value of 6.35 at the bottom.

There are, of course, conditions under which equilibrium cannot be assumed. New sludge may not have had time to produce enough gas to establish equilibrium. But as soon as active evolution of gas has begun saturation can be assumed. Immediately after liming the relation may not hold until the sludge has produced enough CO_2 to convert the lime to bicarbonate, although this should not take long with moderate doses if the sludge is showing much activity. If a digestion tank is stirred vertically, the theoretical variation of pH with depth may not be established, for when a body of sludge is moved from the top to the bottom of a tank the theoretical drop in pH will not occur until the liquor has become saturated with gas at the higher pressure and a substantial evolution of gas has been resumed. This may require several hours or even days if there is little activity in the sludge. If ripe sludge is allowed to stand, with clear liquor at the surface and an atmosphere poor in CO_2 above it, CO_2 will be lost from solution and the pH will rise. But obviously this rise does not indicate any further progress in the digestion. Sludge after being drawn onto beds may give high pH values, but these indicate nothing but the extent to which the CO_2 has been allowed to escape. If the sludge is exposed to the air for a long time the rising pH will cause precipitation of calcium carbonate and magnesium ammonium phosphate and finally the loss of NH_3 will balance the further loss of CO_2 so that the pH will become constant at about 8.4.

Under the foregoing conditions the pH will not have the value required by the theory, since equilibrium does not prevail. Attention is directed to the fact that except in the early stages of digestion, the pH is not likely to tell anything of importance if it is not the pH of the sludge in equilibrium with its gas.

The above discussion relates primarily to separate sludge digestion. Further consideration of conditions will be necessary before any application can be made to Imhoff tanks. Doubtless the pH of Imhoff tanks can be accounted for if all of the factors are correctly evaluated.

Suggestions

During the acid phase of digestion when the concentration of bicarbonate is low, rather small changes in the concentration of ammonia or of volatile acids will cause large *relative* changes in the bicarbonate and hence in the pH. Accordingly, rapid changes in the pH are found in early stages of digestion, and the pH as colorimetrically determined may be a convenient and rather sensitive indication of certain conditions of the sludge. But when the alkalinity is high, when for example the pH is above 6.5, the logarithm of the bicarbonate concentration and hence the pH is affected only slightly by relatively large changes in the acid or basic constituents of the liquor. Therefore the pH is a very poor measure of the condition of the sludge or the completeness of the digestion during the alkaline phase. For separate sludge digestion tanks, a more sensitive analytical measure of the condition would be to determine separately the NH_3 and the volatile organic acids. But this is not a simple procedure for routine tests. The bicarbonate concentration varies principally in accordance with the difference between the ammonia and lime on one hand, and the volatile organic acids on the other; and since the bicarbonate can be determined quite easily and quickly it would seem to be the best simple test. The alkalinity to methyl orange is another test which tells approximately the same thing, giving a result only slightly higher than the bicarbonate in the relatively alkaline sludges (after making necessary conversion of units). Acidity by titration is sometimes reported, but this will not give significant results if CO_2 is lost from solution.

Caution must be exercised in using any of these tests as a comparison of the relative efficiency of digestion in different installations. The ultimate alkalinity depends not only upon the thoroughness of digestion but also upon the original concentration and composition of the sludge; the manner of withdrawing supernatant liquor, etc. The tests are only of value as indicating the course of digestion when other conditions are approximately constant.

For those who wish to make use of the bicarbonate test the following procedure will be found to give satisfactory results in sludge liquor with

the pH above 6.5: Two or three drops of methyl orange solution are added to a ten ml. sample of the liquor, reasonably free from sludge particles. Tenth-normal acid is added from a burette until the indicator is red, and then a few drops in excess, the volume being recorded. The solution is boiled gently for a half minute. If the solution is boiled too long there may be appreciable loss of volatile acids. If insufficient acid is added there may be loss of ammonia. Two ml. of phenol red solution are added and the sample is titrated with tenth-normal NaOH until the indicator begins to change to orange, or until it has a color approximating that of the indicator at the original pH. The volume of acid used, less the volume of base, is numerically 100 times the bicarbonate normality. Multiplying the net volume of acid by 610 gives p.p.m. HCO_3^-, by 440 gives bicarbonate as p.p.m. CO_2, or by 500 gives bicarbonate as p.p.m. $CaCO_3$. It seems desirable to us to report the bicarbonate as p.p.m. CO_2. This is convenient if one wishes to know the total CO_2 in solution, in which case it is necessary only to add the bicarbonate CO_2 to the free CO_2, which may easily be calculated from the partial pressure of this gas in the gas mixture and its known solubility coefficient at the temperature in question. Furthermore, bicarbonate is not separated from the solution as bicarbonate; it does not ordinarily remain as a bicarbonate when the solution is evaporated, and p.p.m. by weight of bicarbonate ion in solution is an imaginary quantity.

If the alkalinity of the sludge liquor is low, or the pH is 6.5 or below, considerable care must be used to bring the solution back to its original pH to avoid serious relative error. The bicarbonate concentration varies somewhat with the pH of the solution due to the shift of other buffering equilibria. The pH to which the solution is returned determines a titration value which gives the bicarbonate concentration at that pH. If one wishes to know the concentration which the bicarbonate had when the liquor was approximately in equilibrium with the gas, then the appropriate pH may be estimated roughly from a preliminary titration or with indicators, and for the back titration one may choose an indicator which will allow the solution to be brought back to the proper pH as accurately as desired. It is also necessary in these cases to cool the solution before back titrating, whereas this is not required for results of moderate accuracy in more alkaline solutions. But if these precautions are observed in the more alkaline solutions as well, a high degree of accuracy is possible in the determinations.

It is not necessary to protect the liquor from moderate loss of CO_2, but if it is allowed to stand in a beaker for more than a few minutes before pipetting a sample, calcium carbonate may deposit on the sides of the beaker, and appreciable amounts of ammonia may be lost after the pH has risen to the neighborhood of 8.0.

As set forth above, the pH may be calculated, if the bicarbonate concentration is known and if the per cent of carbon dioxide in the gas can be estimated. As a matter of fact, it is not likely that more than a very slight error will be made in ordinary cases if any reasonable value between 25 per cent and 35 per cent is assumed. Ideally the ionic strength should also be known. It has been seen that a value of 0.09 could be used for the liquors which were the basis of the experiments described in this article. These liquors came from sludge pumped to the digestors at an original concentration of about 4½ per cent solids. The ionic strength in the later stages of digestion would be expected to vary roughly in proportion to the concentration of the original sludge. But the ionic strength correction is small, and it is probable that in most cases the error will be negligible if the same value of 0.09 is used.

For convenience in calculating the pH by this method, the equation may be written in the form

$$\text{pH} = A + B - C$$

in which A contains the equilibrium constant at the proper temperature, the logarithm of the CO_2 percentage, and the ionic strength correction; B is the logarithm of the bicarbonate concentration; and C is a correction for increase in the total pressure with depth. Values of A, B and C for various conditions are given in the following tables. The values of A are based upon the work of Warberg, *et al.*, with the ionic strength taken as 0.09.

Values of the Term A

Temperature	20% CO_2	25% CO_2	30% CO_2	35% CO_2	40% CO_2	45% CO_2
15° C.—59° F.	3.69	3.60	3.52	3.45	3.39	3.34
20° C.—68° F.	3.73	3.63	3.56	3.48	3.43	3.38
25° C.—77° F.	3.77	3.67	3.59	3.53	3.47	3.42
30° C.—86° F.	3.80	3.70	3.63	3.56	3.50	3.45
35° C.—95° F.	3.83	3.73	3.65	3.58	3.53	3.47
40° C.—104° F.	3.85	3.75	3.68	3.61	3.55	3.50
45° C.—113° F.	3.87	3.77	3.69	3.63	3.57	3.52
50° C.—122° F.	3.89	3.79	3.71	3.64	3.59	3.53

Example: What is the pH at a depth of 15 feet in a sludge tank with liquor containing 1850 p.p.m. bicarbonate CO_2, evolving gas with 32 per cent CO_2 and at a temperature of 27° C. (81° F.)?

$$\text{pH} = 3.58 + 3.27 - 0.16 = 6.69$$

Values of the Term B
Logarithm of Bicarbonate Concentration

HCO_3^- as P.P.M. CO_2	B	HCO_3^- as P.P.M. CO_2	B	HCO_3^- as P.P.M. CO_2	B
200	2.30	1500	3.18	3600	3.56
300	2.48	1600	3.20	3800	3.58
400	2.60	1700	3.23	4000	3.60
500	2.70	1800	3.26	4500	3.65
600	2.78	1900	3.28	5000	3.70
700	2.85	2000	3.30	5500	3.74
800	2.90	2200	3.34	6000	3.78
900	2.95	2400	3.38	6500	3.81
1000	3.00	2600	3.41	7000	3.85
1100	3.04	2800	3.45	7500	3.88
1200	3.08	3000	3.48	8000	3.90
1300	3.11	3200	3.51	8500	3.93
1400	3.15	3400	3.53	9000	3.95

Values of the Term C
Depth Correction, to be Subtracted

Depth Under Surface	C	Depth Under Surface	C
5 Ft.	0.06	25 Ft.	0.24
10	0.11	30	0.28
15	0.16	35	0.31
20	0.20	40	0.34

Summary

The hydrogen-ion concentration of digesting sludge is determined by the equilibrium between dissolved carbon dioxide and bicarbonate ion. The concentration of dissolved CO_2 is dependent upon the composition of the gas being evolved and the bicarbonate is determined by the excess of alkaline substances over the organic and fixed acids.

Samples of sludge liquor shaken with sludge gas until equilibrium was reached showed pH values, as colorimetrically determined, which were in good agreement with calculations based on the bicarbonate equilibrium.

Actively digesting sludge showed pH values which did not indicate any significant supersaturation of the liquor with CO_2. It is assumed that liquor in contact with sludge evolving gas can be considered to be approximately in equilibrium with its gas.

Theoretically the pH should be lower at the bottom of a deep tank than at the surface, although when a sample is brought to the surface the loss of gas should allow the pH to rise toward its equilibrium value at the surface. Tests indicated a small effect in the expected direction.

The colorimetric pH determination may be, if carefully made, a convenient indication of certain conditions in digestion tanks when the sludge is quite acid, but it is at best an uncertain indication of the further progress of digestion after the pH is above 6.5.

It is unlikely that the pH of digesting sludge is ever much above 7.6. Higher values may be obtained if the liquor has been allowed to lose part of its dissolved CO_2.

The pH of sludge during the alkaline phase of digestion tells nothing of importance if it is not the pH of the sludge in equilibrium with its gas.

The determination of the bicarbonate concentration is a simple and sensitive test which may serve to correlate certain digestion phenomena in separate digestion tanks.

If the bicarbonate concentration and the approximate composition of the gas are known, the pH of the sludge in equilibrium with its gas may be easily and accurately calculated.

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THE DETERMINATION OF THE pH OF SEWAGE SLUDGES *

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The pH of sewage sludges is so popular as an index of the condition of the digestion mixture, that a discussion of the technique of this determination may be justified, although there may be some disagreement on the interpretation of the results.

It was early recognized that the electrometric method, using the hydrogen electrode, was not satisfactory on solutions buffered with the carbonate-bicarbonate-carbon dioxide equilibrium as carbon dioxide was swept out of solution by the hydrogen, thus displacing the equilibrium toward the alkaline side. The rocking hydrogen electrode did not improve conditions because the agitation also displaced CO_2 from solution. The quinhydrone electrode has been used with greater success on sewage sludges. However, the authors have found that unless considerable care is taken in rapidly dissolving the quinhydrone in the sludge liquor, without shaking or extensive stirring, the results show a pH 0.2 more on the alkaline than those obtained by the colorimetric method. This is due to a loss of CO_2 in the manipulation of the sample. However, this is a matter of careful technique with any method used and is only mentioned to call attention to the care that should be taken in handling the sludge liquor from the time it is collected until the pH is read so as to minimize the loss of CO_2 from the solution. Glass and antimony electrodes have been developed more recently but have not been, as yet, entirely satisfactory. The electrometric apparatus is costly and except for research and special cases does not justify its use in sewage treatment plants.

The colorimetric determination of pH on sewage sludges is by far the most popular method and when used carefully and with discretion probably gives the most satisfactory results. This method consists in comparing the color produced by a given indicator in the sample with those produced by the indicator in buffered solutions of known pH values, or with standard color solutions, colored glass, color charts, etc., which have the same color characteristics as the standard indicator-buffer solutions. With clear colorless solutions the color comparisons may be made to within 0.1 pH, which is sufficiently accurate for most purposes of plant operation. Variations in the technique and conditions may introduce greater errors.

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Collection of Sample.—The sample must be collected carefully to avoid any unnecessary aeration. The point of collection should be carefully chosen to obtain the information desired, for there may be considerable difference, in deep tanks, between the pH of the partially digested sludge at the surface of the sludge blanket and that of the well digested sludge at the bottom of the tank. Samples may be taken at various depths to determine the extent of well digested sludge in the tank. We collect sludge samples with a pitcher pump connected with a heavy walled 1½ inch hose.

Color and Turbidity.—It is necessary in most colorimetric test sets to compensate for color and turbidity of the sludge liquor or diluted sample by placing a sample of the unknown behind the color standard in the usual way. With concentrated sludges, because of the buffer capacity, the sludge may be diluted with from 1 to about 20 parts of aerated distilled water, settled, and the clear supernatant liquor tested. It is advisable to use as low a dilution ratio as possible to avoid any possible errors that might ensue.

The Chicago Sanitary District set eliminates color and turbidity compensation by comparing the colors in small tubes about the size of 1 c.c. pipettes. With this set, 1 c.c. of sample is sufficient and this amount can usually be obtained from the sludge sample after a few minutes settling without resorting to dilution.

Centrifuging to obtain sludge liquor is satisfactory, but filtration must be condemned because of the possible loss of CO_2 in the operation.

Indicator Solutions and Color Standards.—There is considerable variation in the intensity of the color produced by different indicator salts, particularly when purchased from various manufacturers, or to a certain extent in solutions made up from the same sample, if considerable care is not exercised. For this reason permanent color standards of any type must always be carefully checked whenever a new indicator solution is made up, to be sure that the color intensity produced in the sample is the same as that in the permanent standard. This can easily be done by using a sample of known pH. When using a commercial set, it is well to obtain the indicator solutions from the manufacturer and then to check them for color intensity. Our experience has been that the manufacturers are quite careful to supply good quality indicator solutions for their sets. On the other hand, 0.02 per cent solution of phenol red was purchased from a well-known chemical supply house for use with a glass standard set, and it was necessary to use three times the required amount of the indicator received to produce comparable colors with those of the glass standards. Permanent standards of the solution type should be checked regularly with buffer standards to be sure that no fading or color change has taken place. Experience with glass standards has

shown that they do not fade to any extent but that there is often a slight difference in tint between the sample and the standard. This is not serious in most cases and is not intended as a severe criticism of these standards, for they are quite satisfactory for most work.

The drop ratio method of making up standard colors, which was published in the 5th edition of *Standard Methods of Water Analysis* but omitted from 7th edition, is quite satisfactory when a commercial set is not available and is very handy for checking the pH of buffer mixtures that may be questionable due to impurities in the salts. Hatfield has published a modification of this method which produces standards which are permanent for at least three months. However the method is not as convenient as the commercial sets.

For clear colorless solutions satisfactory results may often be obtained by using the color charts published by Williams and Wilkins, which cost $1.00. These charts are handy to have for rough work and we would not be without them.

We have used, with satisfactory results, the LaMotte, Taylor, Hellige glass, and the Chicago Sanitary District commercial sets. In many ways we like the Chicago Sanitary District set for sewage work the best because it is handy, requires only small amounts of material, requires no compensation for color or turbidity, and is inexpensive to buy and to maintain.

We are now using the Hellige-Klett wedge colorimeter, which operates on the same theory as the drop ratio method in that the acid and alkaline colors of the indicator are superimposed upon each other in a wedge-shaped container. It has numerous advantages that appeal to us personally such as: (1) The color standards are easily made up without using a large amount of buffer mixtures, (2) the standards are made up with the indicator which is being used for the particular test, (3) by using an acid and alkaline buffer for the two colors the standards remain permanent for three months or longer, (4) the whole series of indicator standards are easily available, so that a complete set of color standards to cover the range between 1 to 12 pH is unnecessary and (5) the color can be matched at any point on the scale rather than estimated between two colors which are 0.2 pH apart.

We have not had experience with the Dubosecq type of pH colorimeter that Bausch and Lomb have on the market. It is undoubtedly a high class instrument.

Acidity or Alkalinity of the Indicator Solutions.—The colorimetric method as commonly used is quite satisfactory on well buffered solutions, but when the buffer capacity is greatly reduced, as in distilled water or very soft waters, the acidity or alkalinity of the indicator will have a tremendous effect on the pH of the solution. Acree has shown that for

weakly buffered solutions the pH of the indicator solution should be the same as that of the unknown sample. This necessitates a series of indicator solutions in 0.2 pH steps and is quite laborious but quite necessary for very dilute solutions. Sludge liquors are sufficiently buffered so that this method is unnecessary, but we feel that it is reasonable to minimize this possible error by using indicators which are kept near the mid-point of their pH range. For example we keep bromthymolblue solution so that it is a grass green when drawn up in the pipette, or at about a pH of 7.1 which is the indicator constant. This is done by adding a few drops of 0.02 N acid or alkali to the indicator solution after it is made up, until the green color is obtained. On standing the indicator solution changes color (usually toward the acid side) due to the action of the glass bottle in which it stands. It can easily be brought back to the green color by adding a drop or two of the standard alkali.

Summary

The colorimetric method for determination of the pH of sewage sludges is most satisfactory when reasonable precautions are taken. The authors have indicated some of these precautions which they think are important.

THE QUANTITY OF GARBAGE THAT CAN BE DIGESTED WITH SEWAGE SLUDGE

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The laboratory studies begun several months ago at the Baltimore sewage works on the anaerobic digestion of various mixtures of garbage and sewage sludge have been continued. The results of these preliminary experiments [1] indicated that garbage or a mixture of garbage and raw sludge would digest within 30 to 40 days when kept at a pH value of from 6.8 to 7.2 and at a temperature of 28° C. and when seeded with a sufficient quantity of ripe sludge.

One of the next important steps in these investigations has been to determine the maximum quantities of garbage and raw sludge that can be digested by a given volume of ripe sludge. Laboratory experiments, lasting for a period of over four months, indicate that daily additions of garbage and raw sludge, having a total dry volatile solid content of 4 and even as high as 5 per cent by weight of the dry volatile solid content of the digested sludge, can be digested with the formation of an easily dewaterable end product, which is free from odor.

Description of Experiments

A quantity of digested sludge, which was estimated to be about 50 days old, was obtained from one of the heated sludge tanks at the Baltimore sewage works. This material, which had a pH value of 6.9, contained 52.2 per cent volatile solids, 6.9 per cent ether soluble matter and 89.2 per cent moisture. The sludge was divided into a number of equal portions, each weighing 7,711 grams and containing 434.3 grams of dry volatile solids. Each portion was put into a 5-gal. carboy, into which daily additions of a mixture of garbage and raw sludge were made. The volumes of each of these materials added were adjusted so that they each contained equal weights of dry volatile solids. The total quantities of dry volatile solids added daily amounted to 1, 2, 3, 4 and 5 per cent by weight of the original weight of dry volatile digested solids in each of the carboys. As no additions were made on Sundays or holidays, a double portion of material was added on the preceding day. The bottles were incubated at 28° C. $\pm$ 1°. The materials were digested in two duplicate groups of carboys, and each result is an average of two determinations. In every case the corresponding results were quite uniform.

The raw sludge used was obtained from one of the preliminary settling tanks at the Baltimore sewage works. This material was 5 or 6 days old, and had a volatile solid content which varied from a minimum of 67.2 to a maximum of 86.5 per cent (see Figure 1). The ether soluble matter in the sludge ranged from 24.4 to 56.6 per cent (see Figure 2), and the pH value was 4.9 or less. The garbage, which was obtained from the municipal incinerator, was ground in a food chopper into a pulp before it was mixed with the raw sludge. The volatile matter in the garbage, which varied from 87.2 to 95.7 per cent, was considerably higher than that in the raw sludge. On the other hand, the ether soluble matter and the moisture were less. The garbage was quite acid as indicated by its pH value, which was 4.9—. Once a week sufficient sludge was removed from each of the bottles so that 7,711 grams of wet material, the original quantity started with, remained. Chemical analyses were made of the materials withdrawn. The volumes of gas formed were measured daily, and analyzed at least once a week and generally oftener.

Results

The extent to which digestion progressed was determined by the volatile solid content of the materials in the carboys. The results are shown in Figure 1, which gives the volatile solid content during the first 146 days, when the materials were added daily, and also for the following 27-day period, when no additions were made. With both the 1 and the 2 per cent additions the volatile solid content was practically always below 55 per cent, and with the 3 and the 4 per cent additions the volatile matter was generally below 57.5 per cent. The 5 per cent addition gave a peak of 61.6 per cent volatile matter. Normally, however, with this quantity of material added daily the volatile solids in the digested sludge did not average more than approximately 58 per cent. The ether soluble matter of the materials in the bottles (see Figure 2) usually varied from 5 to 10 per cent. The quantity of scum formation was practically the same as when only sewage sludge is digested.

Although the amount of volatile matter in digested solids is a good index of the extent to which decomposition has progressed, a knowledge of the physical characteristic of the material is also of importance. At all times the appearance of the sludge in all of the bottles was the same. The solids had a dark brown color similar to that of ripe sludge. Furthermore, all of the materials streaked well when allowed to flow over a porcelain plate similar to well-digested Imhoff sludge. The solids in all of the carboys had lost their characteristic odors both of garbage and raw sludge, and had acquired a musty methane odor.

The quantities and the chemical analyses of the gases produced from the digesting garbage and sludge are of considerable interest. Table I

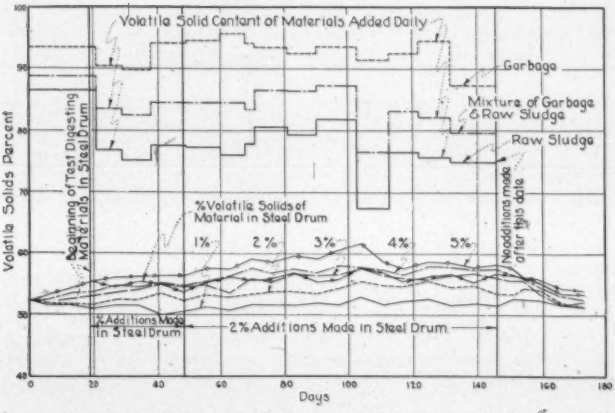

FIG. 1.—Changes in volatile solids in sludge, receiving from 1 to 5 per cent daily additions of a mixture of garbage and raw sludge.

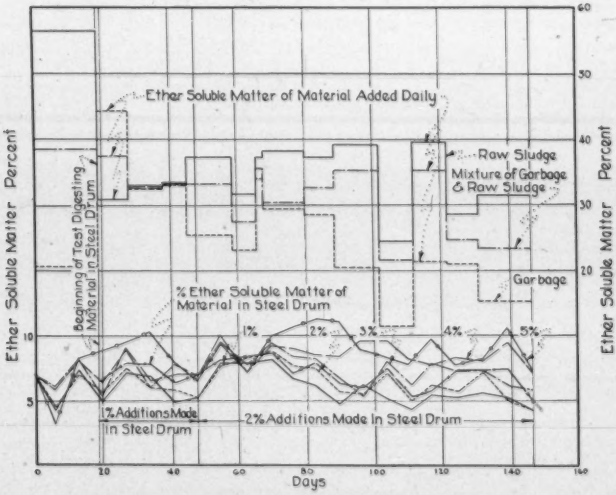

FIG. 2.—Changes in ether soluble matter in sludge, receiving from 1 to 5 per cent daily additions of a mixture of garbage and raw sludge.

TABLE I.—*Quantities of Volatile Matter Digested and Gas Produced from Sewage Sludge to Which Daily Additions of Garbage and Raw Sludge Were Made*

(Digestion in 5-Gal. Carboys Containing 2.04 Gal. of Material)

Quantity of Dry Volatile Solids Added Daily		Volatile Matter Which Was Lost or Disappeared	Gas Production								
			Volume								
							Total		CH_4 Per Gram of Volatile Matter Lost	Total Gas Per Gram of Volatile Matter Lost	Ratio of Weight of Gas Produced to Weight of Volatile Matter Lost
Per Cent of Original Dry Volatile Solids Present	Grams	Grams	CH_4 cc.	H_2 cc.	CO_2 cc.	N_2 cc.	cc.	Grams	cc.	cc.	
1	4.3	523.7	301,350	32,450	159,270	5,720	498,790	539.0	575.4	952.4	1.03
2	9.7	992.1	599,670	34,650	304,250	4,070	942,640	1,035.7	604.4	950.1	1.04
3	13.0	1,431.6	892,820	43,470	447,700	2,600	1,386,590	1,526.6	623.7	968.6	1.07
4	17.4	1,875.9	1,187,070	49,320	583,740	1,960	1,822,090	2,004.5	632.8	971.3	1.07
5	21.7	2,304.6	1,455,730	57,730	708,230	3,300	2,224,990	2,444.0	631.7	965.5	1.06
Average									613.6	961.6	1.05
(Digestion in 33-Gal. Drum Containing 23.5 Gal. of Material)											
1	34.6	888.8	535,140	60,920	294,610	20,430	911,100	993.4	602.1	1,025.1	1.12
2	69.2	5,077.0	3,514,530	280,050	1,817,980	5,870	5,618,430	6,123.1	692.2	1,106.6	1.24

gives the quantities of volatile matter which was lost or disappeared from each group of five carboys during the digestion process, together with the gas produced. The quantities of volatile matter which were lost or disappeared naturally increased in those bottles receiving larger amounts of raw material. A total of 523.7 grams of volatile matter was lost in the carboys receiving 1 per cent additions, and 2304.6 grams were lost when 5 per cent additions were made. The average quantities of total gas and methane produced from all of the bottles were 961.6 c.c. and 613.6 c.c. respectively per gram of dry volatile matter lost. When sewage sludge alone is digested, previous laboratory experiments [2] at Baltimore have demonstrated that the total gas and methane given off amounted to about 1300 c.c. and 780 c.c. respectively per gram of dry volatile matter lost. It is apparent, therefore, that the total gas and methane production per gram of volatile matter lost from a mixture of digesting garbage and sludge is not so great as from sewage sludge. The average ratio of the weight of total gas evolved to the weight of volatile matter lost, as determined from the analytical records, was 1.05. Where sludge is digested by itself, this ratio has been found to be about 1.40 for Baltimore [2] sludge.

The chemical analyses of the gases produced are given in Table II. The percentage of methane given off, which varied from 60.4 to 65.4 per cent, is from 5 to 10 per cent lower than from sewage sludge digested at Baltimore. It is interesting to note that higher percentages of methane were formed in those bottles receiving larger quantities of solids. More

TABLE II.—*Chemical Characteristics of Gases Produced from Digesting Garbage and Sewage Sludge*

Quantity of Dry Volatile Solids Added Daily		CH_4	H_2	CO_2	N_2
Per Cent of Original Dry Volatile Solids Present	Grams	%	%	%	%
1	4.3	60.4	6.5	31.9	1.2
2	9.7	63.6	3.7	32.3	0.4
3	13.0	64.4	3.1	32.3	0.2
4	17.4	65.2	2.7	32.0	0.1
5	21.7	65.4	2.6	31.8	0.2
1*	34.6	58.7	6.7	32.3	2.3
2*	69.2	62.5	5.0	32.4	0.1

* Digestion in 33-gal. drum containing 23.5 gal. of material.

hydrogen was produced than if the garbage had not been present. The volume of hydrogen formed, which ranged from 2.6 to 6.5 per cent, varied inversely with the percentage of methane produced and the quantity of solids added. The summation of these two gases was about the same from all of the carboys, with a minimum of 66.9 and a maximum of 68.0 per cent.

The quantities of total gas and methane produced in the bottles per gram of dry volatile solids added are given in Figure 3. These unit

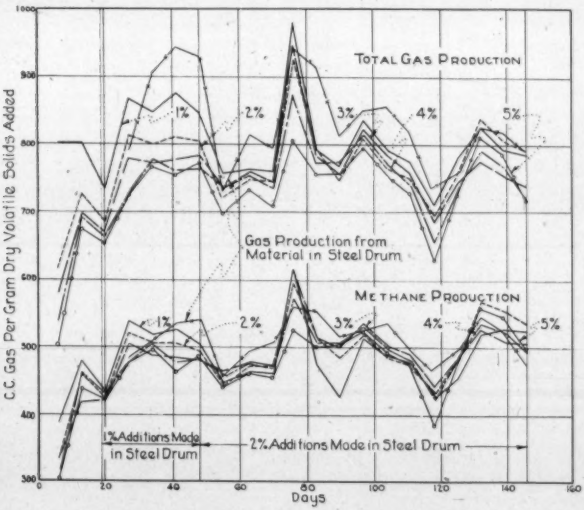

FIG. 3.—Total gas and CH_4 production from sludge, receiving from 1 to 5 per cent daily additions of a mixture of garbage and raw sludge.

volumes varied inversely with the amounts of solids added daily. The one per cent additions generated the largest unit volume of gas, and the 5 per cent additions the least. The average quantities of total gas and methane produced were about 750 to 800 c.c. and 500 c.c. respectively per gram of volatile solids added. As can be seen in Figure 3 the fluctuations in the gas produced were considerable. With 1 per cent additions the total gas varied from a minimum of 710 to a maximum of 980 c.c. per gram of volatile solids added. These variations are most likely due to the changing character of raw solids digested. All gas volumes have been reduced to 0° C. at a pressure of 760 mm. of mercury.

The moistures of the materials in the carboys throughout the experiment are given in Figure 4. There was a gradual increase in the water content of the solids, which indicates the liquefaction of solids. This liquefaction was greatest in the bottles receiving the 5 per cent additions and least in the case of the 1 per cent additions.

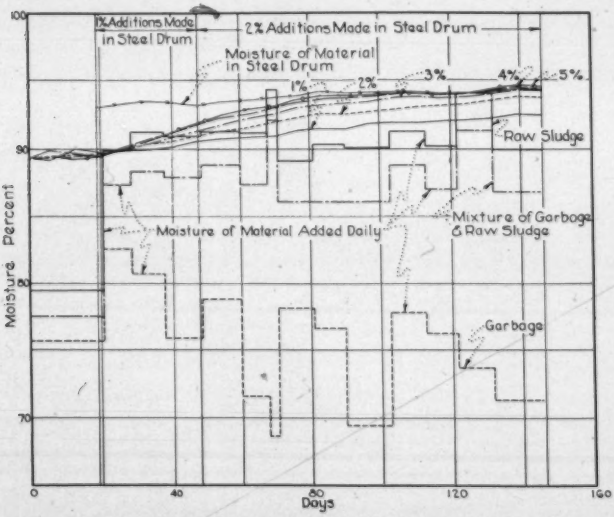

FIG. 4.—Changes in moisture of sludge, receiving from 1 to 5 per cent daily additions of a mixture of garbage and raw sludge.

LARGER SCALE EXPERIMENTS

It was considered desirable to conduct additional experiments on a somewhat larger scale than in the 5-gal. carboys. A covered steel drum with a capacity of 33 gal. was, therefore, used, in which garbage and sludge were digested. The drum was placed in the same incubator with the 5-gal. carboys. On January 25, 1933, nineteen days after the experiments using the carboys were begun, the drum was partially filled with 88,880 grams (23.48 gal.) of digested sewage sludge, which contained 3460.1 grams of dry volatile solids at a pH value of 7.0. From the above date on, the same garbage and raw sludge was added to the bottles and the drum. For a period of 29 days, to February 23, 1933, daily additions of equal quantities of garbage and raw sludge (dry volatile solids

basis) were put into the drum, the amount being 34.6 grams of dry volatile solids, or 1 per cent of the dry volatile solids originally present. From February 24 to June 1, 1933, these daily additions were increased to 2 per cent. Once a week sufficient digested sludge was removed so that the volume of material remaining was the same as at the beginning of the experiment.

The results of the studies are shown in Figures 1, 2, 3 and 4 and in Tables I and II. As indicated by Figure 1, which gives the percentage of volatile matter present during the experiment, the material decomposed quite well. The digested sludge in the drum at the beginning of the experiments contained 55.3 per cent volatile solids. The volatile matter reached a peak of 57.7 per cent 85 days after the beginning of the work while 2 per cent additions were being made. The average amount of volatile matter present during the entire 127-day period was about 56 per cent.

The quantity of volatile matter, which was lost or disappeared together with the gas production, is shown in Table I. During the first 29 days, when 1 per cent additions were made, 888.8 grams of volatile solids were lost and 993.4 grams of gas produced. The gas formed was 12 per cent in excess of the volatile matter lost. For the remaining 127-day period, when 2 per cent additions were being made, 5077 grams of volatile matter were lost, and 6123.1 grams of total gas produced. In this case the gas evolved was 21 per cent in excess of the volatile matter lost. These gas productions—especially with the 2 per cent additions—are considerably greater than those where the garbage and the sludge were digested in the 5-gal. carboys. The only plausible explanation for these somewhat different results is that the former sludge was in a steel drum whereas the latter material was in glass containers. Possibly the steel in contact with the sludge had an accelerating action on digestion. The quantity of methane produced from the sludge, to which 2 per cent additions were made, was 62.5 per cent (see Table II), which was not far different from the percentage of methane in the gas given off by the sludge in those 5-gal. carboys which received the same amount of raw material daily.

As indicated by Figure 3, the total gas and methane produced were generally greater than from the material in the bottles. The total gas production averaged about 850 c.c. per gram of dry volatile solids added, and the average methane production was about 500 c.c. That there was some liquefaction of solids is apparent by Figure 4. The material at the beginning of the experiments contained 93.0 per cent moisture, and after 127 days the water content was 94.3 per cent.

Conclusions

The results of the experiments in so far as the digestion of Baltimore garbage with sewage sludge is concerned indicate the following:

1. A mixture of equal quantities of garbage and raw sludge on a volatile solids basis digests rapidly when seeded with the proper amount of digested sewage sludge and kept at 28° C.

2. Daily additions of as much as 5 per cent of the initial volatile solids, consisting of 2½ per cent garbage and 2½ raw sludge, can be satisfactorily digested with the production of a non-offensive, easily dewaterable end-product.

3. Although daily additions of raw material greater than 5 per cent were not made, it is doubtful whether quantities much larger than this can be digested with satisfactory results.

4. The total gas and methane production was somewhat higher than was previously found.[1] The total gas was about 750 to 800 c.c. and the methane 500 c.c. per gram of dry volatile solids added.

It should be emphasized that all of the experiments, including the digesting of the materials in the steel drum, were on a laboratory scale. Before any final and comprehensive conclusions can be reached regarding the practicability of digesting mixtures of garbage and sewage sludge in considerable quantities, a series of large scale experiments should be conducted at several municipalities over a considerable period of time, preferably with different kinds of garbage and sewage sludge.

As a result of the above studies a temporary grinding station has been erected in the eastern part of the City of Baltimore, where condemned produce or garbage can be ground and discharged into the outfall sewer, adjacent to the station. Equipment is available for the grinding of 20 tons of material an hour.

The Baltimore sewage works, where the experiments were conducted, are under the general supervision of B. L. Crozier, chief engineer, department of public works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent. J. W. Bushman, to whom acknowledgments are due, assisted in the laboratory work.

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DIGESTION OF GARBAGE

By Gordon M. Fair

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The paper on the digestion of garbage with sewage solids by Keefer and Kratz in the January, 1933, issue of This Journal calls to the author's mind an unpublished study of the digestion of garbage completed in his laboratory in February, 1928. It was the intention of this study to determine what would happen to digestion tanks that received the garbage of a municipality as well as its customary load of sewage solids. An error in preparing the mixtures of garbage and sewage solids, however, yielded mixtures in which the ratios of volatile matter were such that the sewage solids did not serve their purpose as buffering media and as a source of adequate quantities of nitrogen. They merely became inoculants of a flora and fauna accustomed to the anaerobic liquid habitat of a digestion tank. The mixtures, therefore, approached those employed by Keefer and Kratz in which garbage was digested without seeding sludge. For these Keefer and Kratz report absence of gas production.

The characteristics of the garbage and sewage solids and the composition of the mixtures employed are given in Tables I and II. Ob-

Table I.—*Characteristics of Garbage and Sewage Solids*

Material	Volatile Solids %	Moisture %	pH
Garbage	91.4	60.0	4.6
Fresh Solids	74.7	97.4	5.0
Ripe sludge	37.8	84.0	6.6

Table II.—*Composition of Garbage and Sludge Mixtures*

Mixture (1)	Garbage Grams (2)	Fresh Solids Grams (3)	Ripe Sludge Grams (4)	Water Grams (5)	Ratio of Volatile Matter (2) : (3) : (4) (6)
Fresh Solids and Ripe Sludge	—	1050	175	375	0 : 2 : 1
Garbage, Fresh Solids and Ripe Sludge	1500	375	65	1060	140 : 2 : 1
Garbage, Fresh Solids and Ripe Sludge, pH Adjusted	1500	375	65	1060	140 : 2 : 1
Garbage and Ripe Sludge	500	—	25	460	120 : 0 : 1

TABLE III.—*Cumulative Gas Production* * *and Hydrogen-ion Concentration* † *of Digesting Mixtures.*

(* Liters per kilogram of volatile solids; † pH)

Elapsed Time, Weeks	Fresh Solids and Ripe Sludge				Garbage, Fresh Solids and Ripe Sludge				Garbage, Fresh Solids and Ripe Sludge, pH Controlled				Garbage and Ripe Sludge			
	Gas Production			pH	Gas Production			pH	Gas Production			pH	Gas Production			pH
	Total	CH_4	H_2		Total	CH_4	H_2		Total	CH_4	H_2		Total	CH_4	H_2	
1	19	12	—	5.8	15	—	1.5	4.4	12	—	1.8	5.4	11	—	—	4.4
2	46	30	—	5.6	17	—	1.7	4.4	18	—	2.7	7.0	13	—	—	4.4
3	75	52	—	5.8	19	—	1.8	4.4	22	—	3.2	6.8	15	—	—	4.4
4	109	71	—	6.3	21	—	2.2	4.1	23	—	3.5	6.5	17	—	—	4.2
5	136	89	—	6.7	24	—	2.6	4.2	24	—	3.6	6.2	19	—	—	4.4
6	144	95	—	6.6	26	—	3.1	4.4	25	0.1	3.6	6.2	21	—	—	4.5
7	145	96	—	6.6	27	—	3.4	4.5	26	0.2	3.6	6.0	22	—	—	4.4
8	163	108	—	6.6	29	—	3.7	4.5	27	0.4	3.6	6.2	24	—	—	4.6
9	191	129	—	7.1	31	—	4.0	4.5	29	0.8	3.6	6.2	25	—	—	4.5
10	222	151	—	6.9	32	—	4.3	4.5	30	1.2	3.6	6.1	25	—	—	4.5
11	241	166	—	7.0	32	—	4.4	4.4	32	1.4	3.6	6.2	25	—	—	4.4
12	263	182	—	7.0	32	—	4.5	4.4	33	1.8	3.6	6.2	25	—	—	4.4
13	266	184	—	7.0	33	—	4.5	4.4	34	2.0	3.6	6.2	25	—	—	4.5
14	266	184	—	7.1	33	—	4.5	4.5	34	2.1	3.6	6.2	25	—	1.5	4.6

Tests were discontinued February 16, 1928.

servations of gas production and changes in hydrogen-ion concentration are presented in Table III. The results confirm the findings of Keefer and Kratz.

In connection with the results reported by Keefer and Kratz, it may be worth while to consider what quantities of garbage and sewage solids may be expected in an average Northern American municipality. The figures in Table IV are given in the literature.

TABLE IV.—*Expected Quantities of Garbage and Sewage Solids in an Average Northern American Municipality*

Material	Per Capita Production Lb. per Year	Moisture %	Volatile Matter %	Authority
Garbage	180	75	90 *	Am. Civil Engineer's Handbook, p. 1751.
Plain Sedimentation Sludge	800	95	70 *	Metcalf and Eddy, p. 680.
Digested Sludge	168	85	45 *	Metcalf and Eddy, p. 680.

* Estimated from various results.

On the basis of these values the expected ratio of garbage to fresh to digested solids is 3.6 : 1.5 : 1. In the light of the results reported by Keefer and Kratz it would appear, therefore, that normally the quantities of sewage solids are inadequate to satisfy the demands for good digestion of all the garbage of a community with its sewage solids. It may be, however, that the material resulting from the digestion of suitable mixtures of garbage and sewage solids can itself serve as seeding material and thus more nearly meet the needs of the process.

Plant Operation

RECENT DEVELOPMENTS IN SEWAGE TREATMENT *

By Harrison P. Eddy

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During recent years relatively few sewage treatment plants have been constructed in the United States, largely due to the prevailing economic conditions. The technical press, however, has contained many interesting articles describing investigations of new processes and improvements to old ones. Much study has been devoted to the treatment and disposal of sewage solids, as well as to the treatment of sewage itself. Among the fields in which there have been significant developments in recent years may be mentioned the following: sludge digestion, mechanical dewatering and incineration of sludge, reduction of biochemical oxygen demand of sewage by chlorination, and chemical precipitation of sewage.

Sludge Digestion

The storage, removal and disposal of the sewage solids deposited in clarification units is an integral part of sedimentation and chemical precipitation processes. In general, these solids are subjected to anaerobic decomposition, or digestion. In the early days of sewage treatment, sludge was subjected to digestion while remaining in contact with the flowing sewage, as in the septic tank. The next development was the two-story settling tank, in which the solids settling from sewage in the sedimentation compartment are digested in another compartment of the same tank. More recently, separate tanks have been developed for the digestion of sludge, thus making the control of the digestion process more practicable. Furthermore, the expense and construction difficulties sometimes incident to the great depth of two-story tanks may be reduced by separating digestion units from sedimentation units.

Temperature of Digestion.—Since digestion is a biologically-activated process, decomposition proceeds most rapidly at temperatures at which life processes of the organisms of decay are most active. Such temperatures are considerably above the average air temperatures of the northern United States. Low temperature retards digestion, necessitating storage of the sludge in the digestion units for longer periods of

* Presented before the Fifth Annual Meeting of the New England Sewage Works Association, Worcester, Mass., October 2, 1933.

time. Therefore, the heating of separate sludge-digestion tanks has come into vogue recently.

A committee of the American Society of Civil Engineers, which has been studying the problem of sludge digestion, finds that up to 125° F., or somewhat more, the time of digestion is decreased as the temperature increases.[1] Information available to the committee in 1932 indicated that temperatures above 80° F. and approaching 100° F. are desirable for digestion.

After a half-year's operation of the new sewage treatment plant at Rome, N. Y., H. W. Taylor concludes that the optimum temperature for sludge digestion appears to be between 78° and 84° F.[2] He reports that after January first the sludge temperature increased rapidly, accompanied by increasing gas production, but that the high temperatures obtained in June, reaching at times more than 90° F., were not favorable to gas production.

Digestion at the higher ranges of temperature is still under investigation. It has been found in some cases that at temperatures between 125° and 135° F. digestion proceeds rapidly, due to the development of heat-loving or thermophilic organisms. On the other hand, Fischer reports that large-scale tests on digestion at 130° F. as compared with 90° at Aurora, Ill., have failed to show a more rapid rate of digestion or greater gas production at the higher temperature.[3] Thermophilic digestion there gave unfavorable results, in that it caused scum formation, increased the hydrogen sulphide content of the gas, produced a digested sludge that was difficult to dewater, and brought about a highly putrescible overflow that would require special treatment before it could be returned to the raw sewage.

Up to the present time data are not available on the operation of large plants which would justify a final conclusion as to the best and most economical temperature for digestion of a given type of sludge. That temperature is appreciably more influential in accelerating the digestion of activated sludge than that of plain-sedimentation sludge is indicated by the studies of Fair and Moore.[4] These authors add, however, that activated sludge does not digest so well in general as plain-sedimentation sludge.

Concentration Prior to Digestion.—Attention has been given recently to the concentration of raw sludge prior to digestion, for the purposes of increasing the average sludge density in the digestion tanks, reducing the volume of overflow liquor, and thus cutting down heat losses. Present indications are that relatively high concentrations can be obtained by means of auxiliary thickeners or decanting tanks. Taylor states that experiments at Rome have shown that fresh sludge concentrates quickly to something less than 70 per cent of its initial value.[2]

It is not desirable, however, for the concentration to take place under exposure to the sun's rays in summer. He believes that it could be accomplished readily in a covered tank within three hours.

Utilization of Gas from Sludge Digestion.—Until recent years little progress was made in this country in utilizing the gases given off during digestion of sewage solids, although their value long has been recognized. When the advantage of heating sludge-digestion tanks to reduce the digestion period was demonstrated, the possible economy of collecting and utilizing the gases of decomposition for heating the sludge was appreciated quickly. The facility with which such gases could be collected in roofed, separate sludge-digestion tanks was a contributing factor in the spread of their utilization. At some plants the gases are used as fuel in gas engines, and the collection and burning of gas in waste-gas burners, either open or enclosed, is considered worth while in some cases, to prevent the possibility of escape of offensive odors, even though the energy of the gas largely is wasted. Other methods of utilizing sludge gas include heating and lighting of buildings, incineration of screenings, operation of gas refrigerators, and sale of the gas to gas companies.

The volume of gas produced in the digestion of sludge depends largely upon the quantity and character of sewage solids digested. Between 8 and 11 cu. ft. of gas commonly is produced during complete digestion by a pound of volatile, fresh sewage solids, settling from domestic sewage. Between 70 per cent and 80 per cent of this gas is combustible, being largely methane. The remainder is chiefly carbon dioxide and nitrogen. Under ordinary conditions of operation, digestion is not carried to completion and only about 75 per cent of the total possible gas evolution takes place. On this basis, an average figure for per-capita gas production may be about 0.4 cu. ft. daily. In the presence of large quantities of organic industrial wastes, however, the average value may be exceeded two-fold or more.

Walraven recently has studied the question of developing power from sludge gas at Springfield, Ill., and is convinced that in many instances cities are overlooking a valuable source of energy by using such gas for heating purposes, instead of as fuel within an internal-combustion engine.[5] At the sewage treatment plant of the Springfield Sanitary District in 1932, sludge was digested in six separate digestion tanks, two of which were covered with floating steel gas domes. The volume of gas collected fluctuated between 30,000 and 65,000 cu. ft. a day, with an average of more than 40,000 cu. ft. a day. Walraven was of the opinion that, if gas covers were placed on two additional tanks and the remaining two uncovered tanks were used for sludge storage only, an average of 50,000 cu. ft. of gas could be trapped daily. He estimated the gross

annual saving by using this quantity of gas as fuel for a combustion engine at $8,300, compared to burning it in a furnace. Since that time an internal-combustion engine using sludge gas as a fuel has been installed at Springfield and is reported to be operating efficiently and successfully.[6] The engine cooling water and exhaust gases are utilized to heat the digesters, and sufficient heat is said to be developed to maintain adequate digestion temperatures. A similar installation has been made at Rockville Centre, N. Y.

At the Sugar Creek plant, Charlotte, N. C., two gas engines are available for utilization of sludge gas, with provision for heating the digestion tanks with engine cooling water.[7] One 225-hp. engine is directly connected to an air compressor, while the other 75-hp. unit drives a sewage pump. McConnell reported that, due to mechanical difficulties, this method of gas utilization has not proved very satisfactory. The cost of maintaining the engines practically wipes out the value of the power produced.

From these examples it is evident that, although the utilization of sludge gas for fuel in internal-combustion engines gives promise of savings in fuel costs, installations must be designed and operated with care in order to insure success.

At Greenwich, Conn., sludge gas is used to operate an Electrolux refrigerator in the laboratory of the Old Greenwich sewage treatment plant.[8] Griffin states that, with a few minor changes to the standard gas burner, the refrigerator has operated perfectly, maintaining a temperature of 40° to 45° F. from June to December, 1933. The quantity of gas used for this purpose is thought to be about 5 cu. ft. an hour.

Mechanical Dewatering of Sludge

Although sewage sludge is dried most commonly on sand beds, other methods of dewatering sometimes are used, such as filtering with or without additional pressure or vacuum, and dewatering in centrifuges. Because of the expense of storage tanks or glass-covered beds for disposal of heated sludge, studies have been made during the past few years at Chicago, Baltimore, and other places, to determine whether partially or wholly digested sludge could be dewatered mechanically by vacuum filters and mechanically dried or destroyed in incinerators, thus eliminating both storage tanks and sand beds.

Filtration of Sludge.—At Chicago, a study was made of the possibility of filtering mixtures of fresh solids and activated sludge, thus eliminating digestion completely. According to Mohlman, the fresh sludge filtered on an Oliver filter at higher rates and with less expense for ferric chloride, used as a coagulant, than the digested sludge.[9] Mohlman states that filtration of mixed fresh and activated sludges

"appears to be preferable to filtration of activated sludge alone. The moisture content is lower, varying from 95 to 97 per cent; vacuum filters can be operated at higher speeds than with the dilute activated sludge."

At Baltimore, a series of experiments was conducted in 1931 and 1932, using two types of vacuum filters, a Genter and an Oliver, to dewater sludge from digestion tanks.[10] Both filters were found capable of satisfactorily dewatering digested sludge. Keefer and Cromwell believe that the merits of the process are sufficiently attractive to warrant the purchase of filtering equipment for Baltimore as soon as funds are available. At this plant digested sludge has been dried on sand beds for many years.

Keefer and Cromwell state that the chief advantage which "sludge filtration affords, as compared with air-drying methods, is that, in so far as Baltimore conditions are concerned, the process is considerably cheaper. Where the sludge is digested in heated tanks, from which the gas is collected, and the material is then filtered, it is always possible to convert the energy in the gas into electric power, which can be used to operate the filters and the auxiliary equipment. Following such a plan should still further reduce the cost of sludge drying, especially where electric power is expensive."

It should be pointed out, however, that the vacuum filters in the Baltimore tests were not as effective in removing moisture from digested sludge as sand beds have proven over a period of years. When ferric chloride was used as a coagulant, the average moisture in the digested sludge cake from the Genter filter was 76.7 per cent and that in the cake from the Oliver filter was about 74.9 per cent. The average moisture in the dried sludge from the sand beds during the 7 years preceding 1932 was only 72.1 per cent.

Sludge Conditioning.—Investigations have been carried on recently at Chicago, among other places, relative to the prefiltration treatment of sludge for the purpose of facilitating filtration. The outstanding value of ferric chloride as a conditioner for sludge was reported by Mohlman and Palmer in 1928.[11] Since then ferric chloride has been used in practically all sewage works where sludge has been filtered on vacuum filters. In the past few years efforts have been made to find some augmenting or cheapening agent to use with ferric chloride. From laboratory experiments made during 1931 and 1932 at Chicago, Mohlman and Edwards have drawn the following conclusions:[12] "Substantial reduction was obtained in the amount of ferric chloride required by fresh sludge, by addition of a small amount, 1 per cent or less, of sodium dichromate. . . . A large saving in ferric chloride on digested sludge was indicated by the use of lime, following ferric chloride treatment, in amounts sufficient to

raise the pH to 9.0 or more. . . . Paper pulp seemed to have some value as a filter aid if used in large amounts, equal to 50 per cent or more of the weight of dry sludge solids. Moderate heating, from 72° to 90° F., before addition of ferric chloride improved filtration of fresh solids quite noticeably."

Genter Process of Elutriation of Sludge.—Experiments were conducted by A. L. Genter at Baltimore during 1933 on the elutriation of sludge preparatory to mechanical dewatering. The elutriation process is based on Genter's conclusions that soluble amino and ammonia compounds in sewage sludge are detrimental to the economical coagulation of the colloids by the chemicals used for conditioning the sludge for dewatering. The object of the process is to reduce the proportion of these "ammoniacal compounds" in the sludge before treating it with coagulants preparatory to dewatering. Elutriation consists in mixing the sludge with sewage, effluent, or water, containing a smaller proportion of the amino and ammonia compounds than is present in the sludge, allowing the sludge to settle, and decanting the elutriating water, thus reducing the concentration of the objectionable compounds. The elutriate is returned to the incoming sewage. The Baltimore tests have indicated that the elutriation of sludge prior to conditioning and vacuum filtration allows a material reduction in the quantity of ferric chloride required for conditioning and produces a substantial increase in the rate of yield of sludge cake.

Spray Drying.—The Industrial Associates, Inc., have developed a process for the drying and eventual incineration of wet sludge.[13] The sludge to be dried is stored in a tank, from which it is fed into a centrifugal spray machine and atomized in a horizontal plane near the top of the spray chamber. The dried product falls to the floor of the chamber and is collected by a revolving rake, which delivers into a central chute, discharging into a car or conveyor. The exit gases, laden with moisture and a certain amount of the dust of the dried product, are carried out of the drying chamber through a duct into a cyclone dust collector. Rudolfs and Cleary report that "at a demonstration of this device at Poughkeepsie, New York, in 1931, the apparatus dried 3 gallons of sludge, moisture content 88 per cent, in one minute." So far as is known, no tests of this process on a large scale have been reported, but an installation was made at Plainfield, N. J., in the latter part of 1933, for the spray-drying of sludge.

Incineration of Sludge

In an attempt to utilize the calorific power of sludge in its disposal, the burning of sludge was attempted at a few places in the United States in the early days of sewage disposal: notably, at Worcester, Mass., in

1891 and at Coney Island, N. Y., for a number of years prior to 1892.[14, 15] This method of sludge disposal, however, has not been employed to any great extent.

Chicago Experiments.—At Chicago within the past few years experiments have been made on the incineration of sludge which had been dewatered by means of vacuum filters.[16] Different types of grates have been tried, in particular the Harrington grate, a movable type which prevents sealing of the grate bars by the formation of a cinder or slag. Pearse reports that "the sludge apparently burns fairly readily, with a minimum odor. With the moisture content around 70 per cent or higher, it is necessary to add some coal or other fuel. . . . An inert cinder-cake residue is left, resembling a clinker, with probably less than one per cent of organic matter, something entirely inodorous, and suitable to dump and forget."

In the process of sludge incineration, Pearse says "there is still the problem of odor. This does not appear insuperable, because the temperature of combustion is planned to be above 1500° Fahrenheit. If sludge is burned at low temperatures, however, around 300 to 500°, tests in the laboratory indicate that objectionable odors will be produced."

A large test plant, with a capacity of 20 to 30 tons daily, was built at Chicago in 1932 and operated for some months, to carry on these incineration studies, a rotary dryer being used to reduce the moisture content of the sludge cake from 80 per cent to 20 per cent, preparatory to incineration. At the end of 1933, this incinerator plant was being replaced with one of a different type.

New Jersey Experiments.—A mechanical method of sewage treatment, obviating any biological treatment process and providing for the ultimate disposal of sludge, has been investigated on an experimental scale at the New Jersey sewage experiment station, in cooperation with the Isbell-Porter Co.[17] It consists of a series of tanks, filled with 1½-in. slag, through which the raw sewage is filtered upward. The sludge-covered slag is removed from time to time and incinerated in a specially designed calciner.

Rudolfs and Hay state that "the field for a system as described would be mainly between plain sedimentation and sedimentation plus trickling filters or activated sludge. . . . The method produced results of about 70 per cent suspended solids reduction and from 55 to 60 per cent reduction in B.O.D. with an application of about 75 million gallons per acre per day. . . . Experiments have shown that about 2 per cent of the slag is disintegrated and can be screened out over a ½-in. screen. . . . The amount of ash to be expected per million gallons domestic sew-

age containing 200 p.p.m. suspended solids and with a removal of 70 per cent would be about 280 pounds or less."

No estimate of the cost of operating such a system on a large scale is reported.

Reduction of Biochemical Oxygen Demand of Sewage by Chlorination

Chlorination of sewage or effluents consists of treatment with chlorine or bleaching powder, for the purposes of disinfection, retardation of decomposition, reduction of biochemical oxygen demand, control of odors or control of *Psychoda*, cleaning of the distribution system and destruction of surface films on trickling filters. Although chlorine may be applied for one or more of the purposes mentioned, all of them may be accomplished to some extent when sewage is chlorinated. The fact that much of the chlorine applied to sewage is used up by unstable sewage matters is reflected in a reduction in the B.O.D. of the sewage. This effect of chlorination has been studied recently by several investigators, and the available data have been reviewed by the Committee on Sewage Disposal, American Public Health Association. This committee has come to the following conclusions:[18]

"1. Chlorination, to give residuals of 0.2 to 0.5 p.p.m. after 10 minutes, produces a reduction in oxygen demand of 15 to 35 per cent; the reduction expressed in p.p.m. being roughly proportional to the quantity of chlorine absorbed.

"2. The evidence indicates a reduction of at least 2 p.p.m. of oxygen demand for each p.p.m. of chlorine absorbed, the reduction expressed in p.p.m. being fairly constant irrespective of the number of days in the incubation period.

"3. The disturbance of the normal flora and fauna in sewage effluents by the addition of chlorine leads to difficulties in the use of the B.O.D. test which will require further research before the proper interpretation can be made of some of the reported results.

"4. Chlorination sufficient to produce free chlorine in a stream receiving the chlorinated sewage or effluent will retard the normal decomposition processes, thereby tending to prevent anaerobic conditions during the normally critical period of rapid oxygen depletion. Such retardation of decomposition permits opportunity for reaeration and additional dilution from tributary streams to maintain aerobic conditions.

"5. In the case of a stream containing extensive sludge deposits, the effect of excess chlorine carried in a sewage effluent may be negligible in so far as the maintenance of aerobic conditions is concerned."

Chemical Precipitation

Chemical precipitation is a method of increasing the sedimentation of suspended matter and inducing that of colloidal matter by the addition to sewage of chemicals that in one way or another form "floc" in the liquid, the floc drawing to itself the substances that it is desired to remove from the sewage, or being produced by these substances. Sludge is produced in great quantity, often reaching 5,000 gallons of sludge with 7.5 per cent solids for each million gallons of sewage treated. Furthermore, the effluent ordinarily has been putrescible and not comparable with the effluents produced by oxidation processes. These drawbacks, together with the expense of the chemicals, have curtailed the use of chemical precipitation and have led to its abandonment in most of the American municipal plants formerly employing the process, notably those at Worcester, Mass., and Providence, R. I.

A number of works in Great Britain, however, still employ chemical precipitation. A patent, obtained by Rudolfs in 1931 and assigned to the National Aluminate Corp., covers a process of treating sewage which comprises adding to it soluble iron salts in the proportion of 3.5 to 5.0 p.p.m., and during the past two years several processes of sewage treatment, all employing chemical precipitation, have been the subject of experimentation and have been given some prominence in the technical press.

Laughlin Process.—In 1932 a sewage treatment plant using a chemical precipitation process developed by W. C. Laughlin was put into operation at Dearborn, Mich.[19] Here the substances added to the screened sewage have been varied from time to time, but in general are pulped waste paper, lime and ferric chloride. The effluent from the two precipitation tanks is subjected to rapid upward filtration through a thin layer of magnetite sand, which is cleaned periodically by a traveling magnetic device. The final effluent is chlorinated and the sludge is dewatered by vacuum filtration. Sludge from plain sedimentation tanks at another treatment plant is discharged into the sewage entering one of the chemical precipitation tanks.

From October, 1932, to February, 1933, the Dearborn plant treated an average of 2.85 m.g.d. of sewage from the West Side area and 0.25 m.g.d. of sludge from the East Side sedimentation tanks.[20] During this period the plant effected reductions of 95 per cent in suspended solids and 88 per cent in B.O.D., based on the composite analysis of incoming sewage and sludge. Because of a contract for disposal of sludge from the East Side plant, the Dearborn chemical plant is rarely operated on sewage alone. However, for a period during June and July, 1932, West Side sewage alone was treated. The results obtained during 26 days, "be-

lieved to be more nearly representative of normal sewage with the proper lime dosage," have been reported by Zack.[21] The reduction of suspended solids was from 212 to 20 p.p.m., or 91 per cent, and of B.O.D. from 112 to 38 p.p.m., or 66 per cent.

In Miller's opinion,[20] this plant "provides a degree of treatment that is far in excess of that provided by plain sedimentation. In fact, it is sufficiently high to approach that of the activated-sludge process or trickling-filter installations, although it is still somewhat below them."

Guggenheim Process.—Another chemical precipitation process, which is still in the experimental stage, has been developed recently at the Guggenheim Laboratories.[22] This process consists essentially of four steps:

1. Removal of suspended solids by coagulation with iron compounds and lime, and settling the coagulated solids in the form of a sludge.
2. Disposal of the sludge by filtration and complete incineration. Regeneration of the iron as ferric sulphate from the incinerated ash.
3. Removal from the chemical effluent of the basic nitrogen compounds, together with attendant groups containing carbon, hydrogen, sulphur, etc., by an exchange reaction using zeolite.
4. Regeneration of the zeolite and thereby concentration of the basic nitrogen compounds in the salt solution, and subsequent recovery of ammonia from this solution.

As a result of operating a model plant of this type in New York City for 24 hours a day for about eight months, Gleason and Loonam have reported a removal of suspended solids and B.O.D. of 99.5 per cent and 96.7 per cent, respectively.[23] Their study leads them to believe that "one of these plants, with a capacity of 50,000,000 gallons or more per day, can be installed at a cost of approximately two-thirds of the cost of an activated sludge plant of corresponding capacity."

With regard to cost of operation, Gleason and Loonam report as follows: "Our estimates indicate that the cost of operating and maintaining a chemical process plant with a daily capacity of 50,000,000 gallons or more would be about $22.00 per m.g.d. (In this figure, no credit is taken for the ammonia recovered and no account is taken of interest or amortization charges.)"

The operating results obtained during six months' operation of a 28,000-g.d. Guggenheim plant at the North Side sewage treatment works of the Sanitary District of Chicago have been reported by Gleason and Loonam.[24] Iron and lime were added at the rates of 29.6 and 50.0 p.p.m. respectively. The plant effluent showed an average reduction of 90.8 per cent in the 5-day B.O.D. and an average removal of suspended solids amounting to 97.7 per cent. The moisture in the sludge from the

clarifier was reduced by a thickener and a vacuum filter from 95.2 per cent to 76.4 per cent prior to disposal of the sludge in a rotary dryer and incinerator.

Gleason and Loonam point out that, as compared with the activated-sludge process, the Guggenheim process has the advantage that the sludge produced is discarded, so that temporarily unfavorable conditions, if they occur, have no prolonged effect.

Putnam Process.—Experiments have been carried on lately by A. R. Putnam at Valparaiso, Ind., in which the sewage first receives ground charred sludge from the incineration of the sewage solids.[25] It then enters a receiving well, where about 5 per cent of the sludge previously removed is returned to the sewage. Milk of lime is then introduced. Ferric chloride is added as a coagulant, and the sewage is pumped into a mixing trough and passes into vertical-flow sedimentation tanks. The effluent is aerated, treated with a sterilizing agent and discharged into a sterilizing tank, the bottom of which contains a half-inch of charred sludge supported by a 16-inch layer of sand, if filtering is thought necessary.

The sludge is dewatered by a vacuum filter, dried and charred in a retort. The charred sludge is ground and screened to 200-mesh, and applied to the raw sewage.

Ferric Chloride Treatment.—Another chemical-precipitation process which has been carried on experimentally within the past year involves the use of ferric chloride. From August, 1932, to January, 1933, a small sewage treatment plant was operated by the Great Western Electro-Chemical Co. at Palo Alto, Cal., with the object of determining the effect of the use of ferric chloride in coagulation, and the practicability of regenerating a spent coagulant through the use of chlorine.[26]

In regard to the latter point, it was found that, as regeneration of the coagulant continued, a point finally was reached when the floc would not settle out. Furthermore, the chlorine demand of the spent coagulant increased with each successive regeneration.

At Grand Rapids, Mich., Eldridge and Damoose have studied the feasibility of adding ferric chloride to sewage during short periods of the year in the existing settling tanks, for the purpose of improving oxygen conditions in the receiving stream by removal from the sewage of greater proportions of the solids and oxygen-demanding materials than the treatment plant normally removes.[27] They report that the application of ferric chloride in amounts up to 10 p.p.m. showed an increase in the removal of suspended solids and a reduction in the B.O.D. and chlorine demand. During the eight days of ferric chloride treatment the increase in dry solids removed as sludge was 17.8 per cent. Eldridge and Damoose conclude that the use of ferric chloride during

short periods of the year may be justified, if conditions in the stream approach the critical stage.

Paper Pulp Filtration.—At Rockville Centre, New York, vacuum filters have been installed, to filter the effluent from an activated-sludge plant to the volume of 3 m.g.d., as well as to filter a like volume of effluent from primary settling tanks preceding activation. The process involves a modification of chemical precipitation, in that paper pulp is added to the sewage before filtration, the paper coagulating the suspended solids to form a mat on the filter. The purpose of the installation is to reduce the quantity of suspended solids reaching the sand filters, which form the final step in the sewage treatment process.

W. G. Taylor describes the method of paper pulp filtration as follows:[28] "Pulp made from waste paper may be pumped into the filtering equipment and there disseminated through the incoming sewage: upon application of vacuum the mat is formed. The same pulp may be used and re-used throughout many cycles of operation. On the average the mat may be said to consist of three-quarters paper and one-quarter sewage solids." When the cake contains approximately equal parts of paper pulp and foreign solids, "the entire charge of pulp, together with entrained solids, should be removed from the filter and a fresh charge of pulp admitted." Waste cake is dewatered by vacuum filtration and incinerated.

In operating a vacuum filter for sewage treatment, Taylor states that "some particular sewages which are acid in nature may require adjustment of pH value to prevent the formation of gelatinous films, which have a tendency to reduce the porosity of the paper pulp, making it impossible to maintain a satisfactory rate of filtration." For this reason a lime-feed machine has been installed in the filter plant at Rockville Centre.

Other Processes.—Other chemical-precipitation processes on which development work has been conducted recently include the following;[29] the Lewis process, using ferric chloride, lime, cement dust and ferrous sulphate; the Travers process, using ferrous sulphate, lime, marl and alum; the Diamond Alkali process, using chlorine, ferric chloride, and/or lime; the Streander process, using ferrous sulphate, lime and air; the Miller-Koller process, using lime, copper sulphate, sodium carbonate, sodium aluminate and chlorine; and the Scott-Darcey process, using iron and chlorine.

Conclusion

Perhaps the most significant developments in sewage treatment during recent years have been the investigations into the feasibility of the mechanical dewatering and incineration of sludge, and the change in

status of the chemical precipitation of sewage from an outmoded process to a fruitful field of study.

If full-scale operation of mechanical dewatering and incineration of sludge over a period of years proves the value of this method, the present well-established methods of sludge drying and disposal may be superseded. In fact, it is possible that sludge digestion may be eliminated by dewatering and burning undigested sludge.

With regard to the many processes of chemical precipitation which have been mentioned, practically all are still in the experimental stage. Until sufficient time has elapsed for the accumulation of adequate data on the efficiency and operating cost of these new chemical-precipitation methods, based on the operation of full-scale plants, it will be hazardous to predict whether or not chemical precipitation will return to the favor in which it was held during the early days of sewage treatment.

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OPERATION OF THE SEWAGE TREATMENT WORKS AT SCHENECTADY, N. Y., FOR THE YEAR 1933

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General

A survey of the accomplishments of the past year, with regard to the sanitary disposal of the city's sewage now tributary to the sewage pumping station and the sewage treatment works, indicates that the high standard of efficiency of the past eighteen years has been maintained and that gratifying advances have been made in operation economies.

The sewage has been handled at the Ferry Street Station with highly satisfactory pumpage efficiencies. The treatment devices at the sewage works have accomplished highly satisfactory sedimentation of the sewage solids and oxidation and stabilization of the effluent have reached new levels of efficiency. The methods and results of operation have continued to merit the approval of the New York State Health Department.

The objections which have been raised to sewage treatment in Schenectady became crystallized during the past year. The argument that Schenectady should discontinue treatment because other cities are now discharging raw sewage into the stream has led, naturally, to the suggestion that efforts be made to force other Mohawk Valley cities into a program of sewage treatment. The Mohawk Valley Towns Association has appointed a committee to investigate this sanitary matter, following the suggestion by the Schenectady Bureau of Municipal Research. Such action is highly creditable and desirable.

Proposed Reconstruction

During the past year, all the engineering work has been accomplished in connection with the re-design of the existing works into a separate sludge-digestion plant of adequate size to handle all of the sewage of the city. This is gratifying to the writer in view of his constantly repeated recommendation that Schenectady should provide for the present and future sewage treatment needs. The policy of giving but sixty-odd per cent of the city's sewage adequate treatment and permitting the balance of the flow to enter the Mohawk River untreated has long been a source

Editor's Note.—Mr. Cohn was awarded the Kenneth Allen Memorial Award for 1933 by the New York State Sewage Works Association, for the best report on sewage works operation in the State of New York. The 1932 report, for which the prize was awarded, was abstracted in This Journal, 5, 736 (July, 1933). Mr. Cohn's 1933 report is published here in full.

of dissatisfaction to those interested in stream sanitation and the safety of down-stream communities.

The reconstruction plans have received the approval of the New York State Health Department and permit has been issued for the treatment and disposal of the final effluent in accordance with the proposed plans. Application for federal grant and loan to the amount of $170,000 has been made to the Public Works Administration and it is hoped that speedy approval of the request will be received. It is estimated that work can commence within a month of the receipt of government approval and that reconstruction will require six months. The proposed construction work has received the approval locally from the Common Council, the NRA-Public Works committee and the Schenectady Trades Assembly as a worth-while unemployment relief project.

The plans call for the conversion of the existing hand-cleaned bar rack into an automatically operated mechanical unit. Six of the existing Imhoff tanks are to be converted into mechanically-cleaned settling tanks. The flow line of the tanks will be materially lowered and trunk sewer surcharge, even at flows of 30 m.g.d., will no longer prevail. This expedient overcomes the necessity of expensive trunk sewer reconstruction or augmentation and makes the present conduit capable of handling all the sewage of the city. Velocities of flow in the trunk sewer will prevent a recurrence of the present dangerous condition, which permits deposition of solids. Interceptor surcharges will be prevented at the present points of dangerous overflow and the general operating conditions of the sewerage system and treatment works will be improved and made more economical.

Two heated digesters 60 ft. in diameter will be constructed and the present half-battery of Imhoff tanks will be converted into sludge storage tanks. A new pumping station will be constructed for the purpose of delivering sludge to the digesters and for recirculation of sludge. The existing digested sludge pumping manhole will be reconstructed to suit it for the new task of pumping all sludge to the drying areas.

The gas collected in the digesters and storage tanks will be used for the generation of power by use of a gas engine. An alternate proposal would produce steam in a high-pressure boiler located in a new power station. The steam would operate a turbo-generator set which would supply the plant with light and power with the use of only a portion of the gas available and supply heat for the plant building. The balance of the gas will be stored in a gas holder. Production of 100 per cent of available power could supply other city needs.

The existing battery of new sludge beds will remain and be augmented by an acre of sludge beds constructed on two units of the present trickling filters. No secondary treatment will be required.

Many other innovations are to be provided in the reconstruction. Alternative proposals call for the installation of a screenings incinerator and a small sludge vacuum filter.

Sewage Treatment Plant

The continuation of the operation of the treatment units of the sewage treatment works resulted in the clarification and stabilization of the major portion of the city's sewage flow. The difficulties of operation, as in the past, centered around the trunk sewer and the Imhoff tanks. Operation of the trickling filters, dosing tanks and sludge beds continued under normal conditions.

Further reductions in operating costs were possible during the year and budgetary provisions for 1934 are below those made for the past year.

If the coming year sees the cessation of Imhoff tank trickling filter operation in Schenectady, the works can close its eighteen years of service with a record of splendid accomplishment. The control of a difficult, overloaded works, the maintenance of conditions which have made the plant a good neighbor, the accumulation of much basic data which have served as the basis of new plant design and the maintenance of records upon which the operation of the works can receive sanitary and economic rating—all these accomplishments have given Schenectady a recognized place in the history of advancement in sewage disposal.

The writer would be lax in his duties if he did not point out the value of technical control of a technical process. It may at times appear to be simpler, less trying and more economical to dispense with record-keeping, laboratory control, sanitary perfection, difficult research, and those other phases of works operation which lie close to the heart of the true sanitarian. The far-sighted program, however, always proves the ultimate economy of technical supervision. Schenectady's past policies will pay dividends. The design of the proposed new works on the basis of data collected by the writer has saved the City of Schenectady many thousands of dollars because complete technical knowledge of sewage and flow characteristics, digestion variations, stream conditions and abilities and limitations of existing facilities, has made possible more intelligent solution of the problem.

Sewage Flow.—The sewage delivered to the treatment units consisted of pumped flow from the sewage pumping station and gravity flow tributary to the trunk sewer. As in the past, the sanitary flow was sharply sensitive to ground and storm water conditions. Each storm or thaw resulted in increases in flow which surcharged the overloaded trunk sewer. Sewage was spilled over an emergency overflow weir at the College Creek in order to protect the Front Street section from

flood damage. It was often necessary to pull planks from this overflow in order to lower the sewage in the Front Street interceptor.

A total of 3,260 million gallons of sewage were delivered to the plant for treatment during the year. The average daily flow was thus 8.93 million gallons, the highest flow ever experienced by the units. (Table I.) The maximum monthly average flow was 9.3 m.g.d. experienced in

TABLE I.—*Sewage Treatment Works, Schenectady, N. Y. Operation Data, 1933*

Month	Sewage Flow		Temperature-Fahrenheit				Precipitation	
	Pumped M.G.D.	Treated M.G.D.	Crude Sewage	Tank Effluent	Filter Effluent	Air	Rain or Snow	Inches
Dec. '32	5.9	9.0	52.2	51.9	49.0	30.2	R. & S.	1.20
Jan. '33	5.8	8.8	50.4	50.0	47.6	33.4	R. & S.	1.56
Feb. '33	5.7	8.9	49.3	48.6	45.8	27.1	R. & S.	1.83
Mar. '33	5.5	9.1	46.7	46.5	44.5	31.3	R. & S.	4.81
Apr. '33	5.5	9.0	48.3	48.5	48.7	48.2	R. & S.	4.85
May '33	5.4	8.8	53.3	52.1	56.1	61.1	R	2.80
June '33	5.6	9.2	58.6	59.3	61.6	71.1	R	2.15
July '33	5.1	8.3	62.5	63.1	65.0	75.2	R	0.96
Aug. '33	5.5	9.3	62.8	63.5	64.9	69.3	R	6.31
Sept. '33	5.4	9.0	60.5	61.1	61.9	64.1	R	6.10
Oct. '33	5.3	8.6	58.9	58.6	57.5	46.9	R	1.93
Nov. '33	5.9	9.0	55.8	54.6	51.3	31.0	R. & S.	1.16
Average	5.5	8.9	54.9	54.8	54.5	49.1	R. & S.	35.66

August during a period of excessive precipitation. The minimum monthly average flow was 8.5 m.g.d. experienced in July, a month of subnormal precipitation, thus indicating the effect of rainfall on sewage flows.

The effect of the spill weir in ironing out flow fluctuations can be readily seen from the fact that the range of flow from monthly maximum to monthly minimum was only 0.8 m.g.d. The daily maximum for the year was 10.5 m.g.d. and the minimum experienced during normal operation of the station pumps was 6.8 m.g.d.

The sewage maintained its usual uniformity of character. In general, the sewage for the year 1933 was stronger than in the previous year. Industrial waste was absent but much troublesome oil and petroleum waste was present. The sewage contained appreciable amounts of dissolved oxygen during the day hours but a tendency toward septic condition was experienced during the early morning periods.

A survey of the trunk sewer, carried out in conjunction with flow studies made in the conduit, indicated that deposition of solids in the invert was progressing. It was found that this clogging action was removed to some extent by the more rapid flows resulting from heavy rains and the consequent increased head on the trunk.

Stationary Bar Rack.—All sewage entering the plant passed through the hand cleaned bar rack having 1½-inch clear openings. A total of 173.5 cubic yards of trash were removed from the bar rack during the twelve-month period. (Table II.) All trash was disposed of by plowing under the soil. It was found possible to continue the plowing operation during the winter months, because of periodic thaws. No storing of screenings at the dump trestle was necessary, this being the first year that such procedure was found possible. A reduction in rat breeding naturally resulted.

No odors emanated from the screenings piles awaiting covering. It was found possible to re-use the plowing ground used three years ago because of the rapid conversion of these solids into humus.

Imhoff Tanks.—Operation of the Imhoff tanks continued in the same manner found necessary in the past years. The shallowness of the tanks and the high solids load delivered by the excessive amount of sewage flow of high strength resulted, again, in the rapid accumulation of undigested solids in the sludge and scum compartments. In spite of these conditions, it was found possible to hold solids deposition in the sedimentation compartments to minimum amounts.

Because of the warmth of the winter of 1932–33, more active digestion took place. Some foaming was actually experienced during January and February, 1933. Scum hosing was carried out as an experiment in January and 350 cubic yards of partially digested sludge was drawn to one sludge bed and to the lagoon. A program of slot chaining and curtain wall squeegeeing was carried out.

With the advent of spring, the active hosing of the gas vents was started and the removal of sludge from the tanks began in May. From then until November, sludge drawing was as rapid as sludge drying permitted. In addition to the January experiment, a total of 11,976 cubic yards of wet sludge were removed from the tanks during the regular season. Of this amount 11,276 cubic yards went to the drying beds and 700 cubic yards were lagooned. While the total sludge removal was somewhat lower than in 1932, the amount dried on the beds was slightly greater.

Sludge drawing reached a maximum in July when 2372 cubic yards were pumped to the beds. The wet weather of August, September and October delayed sludge drying and reduced the rate of solids removal from the tanks.

TABLE II.—*Sewage Treatment Works, Schenectady, N. Y. Operation of Treatment Units, 1933*

Month	Bar Rack		Imhoff Tanks				Sludge Beds	Trickling Filters		
	Screening Removal		Efficiency Removal of			Sludge Drawn Cu. Yds.	Dry Sludge Removed Cu. Yds.	Nozzles Cleaned		Stability
	Cu. Yds.	Cu. Ft./ M.G.	Suspend. Solids	Suspend. Alb. NH_3	Settling Solids			Per Day	Per M.G.	Per Cent
Dec.	16.0	1.5	78.2	49.9	93.5	—	—	123	14	97.5
Jan.	16.0	1.6	78.0	51.7	97.5	—	—	103	12	98.2
Feb.	14.0	1.5	78.2	55.0	93.0	—	—	110	12	96.6
Mar.	17.0	1.6	74.4	57.4	88.5	—	—	108	12	99.1
Apr.	12.0	1.2	72.1	50.0	85.9	—	—	98	12	91.9
May	12.0	1.2	73.2	57.4	87.8	1,660	160	120	14	70.9
June	16.0	1.6	65.5	50.0	89.1	2,140	620	102	11	81.8
July	11.0	1.1	71.9	44.5	90.1	2,372	695	91	11	100.0
Aug.	18.0	1.7	73.0	39.0	84.5	1,810	492	91	10	100.0
Sept.	16.5	1.6	68.6	48.7	88.8	1,503	407	83	9	100.0
Oct.	10.0	1.0	73.5	49.2	92.0	1,291	361	91	11	100.0
Nov.	15.0	1.5	71.0	48.0	85.8	1,200	350*	155	17	100.0
Average	14.5	1.4	73.1	48.9	89.7	—	—	106	12	94.7
Total	173.5	—	—	—	—	11,976	3,085	—	—	—

* 200 yds. sludge awaiting removal.

The Imhoff tanks continued to perform their sedimentation functions with highly satisfactory efficiencies, despite the solids overload and the upsetting action of intensive water flushing of the gas vent accumulations. The over-all yearly removal of 73.1 per cent of the suspended solids and 89.7 per cent of the settleable solids in the crude sewage is an accomplishment which would be creditable in settling units which are free from the recognized clarification difficulties of the Schenectady units.

The tanks reached their maximum efficiency of removal of suspended solids in December when the tanks were free from solids load and 78.2 per cent of such solid matter was removed by clarification. The minimum efficiency was experienced in June during the heavy scum hosing period. It is worthy of note that the minimum removal of suspended solids was 65.5 per cent and that ten months show removals over 70 per cent.

The removal of settleable solids, the true index of tank efficiency, was high during the whole year. Maximum removal of 97.5 per cent was obtained in January. The minimum was 84.5 per cent in August. Five months show removals over 90 per cent.

The operation of the Imhoff tanks with such high efficiencies was the result of the extreme care with which the units were handled. Winter operations involved the prevention of belching of solids to the tank surfaces and their exit with the effluent. Incipient foaming was prevented in the summer season by sludge removal and scum hosing. Auxiliary screens were constantly in use at the effluent weirs and never removed during seasons of heavy clogging unless backed up by a secondary screen. Flow reversals were planned to take advantage of the action of the wind in keeping solids swept to the influent end of the tanks.

The study of sludge compartment temperatures, after being carried out for several years, was discontinued. The observations have resulted in interesting and valuable data. Sludge temperatures have remained in the 50° F. range during the winter and early spring and have then risen gradually to the low 70's in the late summer. The temperature ranges have explained the reason for cessation of digestion in the winter and the reason for the rapid digestion of the heavy mass of sludge as the temperature rose. Controlled digestion will rectify the conditions so clearly explained by the sludge temperature records.

Sludge Drying.—All sludge left on the drying beds in the fall of 1932 was removed by farmers at the usual price. The saving in labor and team hire amounted to over $250. It was possible to utilize this labor in emptying the tanks and clearing the beds for the much-needed early spring solids removals from the overloaded hoppers. The sludge

was removed, in major extent, in the frozen state and the farmers were later pleased to take the bed-rakings.

During the summer months, a total of 11,276 cubic yards of satisfactorily digested sludge were pumped to the beds. Beds were dosed 96 times, giving 9.6 fillings per unit, despite the wet weather. Depth of application varied with the consistency of the sludge, the expected drying weather and the estimated speed of the cleaning crew. The major amount of sludge was applied to the beds to a depth of 10 inches and dried to a cake of over 3 inches in thickness.

A total of 3085 cubic yards of air-dried sludge were removed from the beds, directly into farmers' trucks or into the city wagon, for hauling to the storage piles. In addition 200 cubic yards of wet sludge are still on the beds awaiting removal during the usual winter sales period. The sludge removed from the beds during August, September and October was particularly wet as a result of the rainy season. The sludge stored in the field shrank in volume as the moisture content was reduced by drainage and evaporation. The dump wagon often emptied over the same row as many as four times.

The sludge drawn to the beds contained an average of 94.64 per cent moisture, 65.19 per cent organic matter. The average gravity was 1.006 and the pH 6.8. Vigorous hosing often resulted in the removal of grease curd and other evidences of floating scum with the sludge.

Sludge sale was again active with all stored sludge gone by early fall. The continued demand for sludge by the same customers and their neighbors is encouraging evidence of the effectiveness of the material as a fertilizer.

Trickling Filters.—The trickling filters experienced the best period of nitrification efficiency in many years. The final effluent entering the river was highly stabilized during the major portion of the twelve months and the suspended solids were unusually low.

As a result of the filtration of all tank effluent, the final effluent contained a yearly average of over 7 p.p.m. of oxidized nitrogen. The average 5-day B.O.D. of the effluent was 19 p.p.m., equivalent to a reduction of 76.9 per cent through the filters and a reduction of 84.0 per cent through the complete plant.

Suspended solids averaged 31 p.p.m. for the entire year, a reduction of 32.7 per cent through the filters. In spite of this reduction of suspended solids and the absence of unloading, no bed clogging was noted and no surface pooling was evident during the entire period. The amount of humus-like solids in the effluent remained unusually constant but was always visible in appreciable amounts. No secondary sedimentation is provided at Schenectady.

The methylene blue stabilities of the effluents from the three galleries reached new maximum values. The average stability was 94.6 per cent, the highest ever recorded in Schenectady. The lowest stabilities came in May as in 1932. In both instances, the low efficiences were due to frequent back-flooding of the filters by river fluctuations. During July, August, September, October and November the stabilities of all samples tested were over 14 days. During five other months, the stabilities were over 90 per cent.

Psychoda were kept under control by means of periodic flooding and the auxiliary flaming of flies on the gallery walls. During the summer season, the beds were flooded weekly. In spite of this consistent program of submergence, the beds did not suffer decreases in nitrification efficiency. Even the day after flooding, stabilities were maintained at 100 per cent.

The beds were free from pooling at all times. Nozzle clogging amounted to 106 per day for the entire year, or 12 per million gallons of sewage filtered. The low nozzle clogging resulted from the care devoted to tank operation, balancing to some extent the higher cost of this latter service.

Surface gelatine was removed once during the summer by resting the beds. Nozzles were washed twice during the winter months to improve distribution and reduce clogging. Ice formation on the beds was markedly reduced after the nozzles were cleared of gelatinous films. Ice formation reached a maximum of 20 per cent of the bed space during the coldest weather.

Emergency Pumping Station.—It was again necessary to operate the emergency pumping station for the purpose of evacuating the effluent from the filters during the freshet periods in the river.

An important repair was carried out on the main outfall gate at the station which necessitated the operation of the pumps to lower the sewage level in the outfall line during the summer.

Laboratory.—The services rendered by the laboratory to the Public Works Department have been limited to material testing and construction control. In addition, the laboratory carried out its original function of process control of the treatment units. No studies of special sewage problems were possible. The following tabulation gives the average constituents in the raw sewage, tank effluent and final effluent for the year 1933:

Constituent	Crude Sewage	Tank Effluent	Final Effluent
	Parts Per Million		
Free Ammonia	12.4	15.2	5.9
Albuminoid Ammonia—Total	5.81	3.95	2.69
Albuminoid Ammonia—Susp.	3.82	1.94	1.75
Nitrites	—	—	0.677
Nitrates	—	—	6.702
Chlorides	36.4	34.2	32.3
Total Solids	556	431	383
Suspended Solids	172	46	31
Settling Solids	141	—	—
Dissolved Oxygen–% Saturation	10.6	18.3	37.1
Biochemical Oxygen Demand	119	82	19
pH	7.2	7.2	7.1

Odor Control.—Odor control is practised in Schenectady as a matter of necessity. The proximity of residences and commercial establishments, the prevalence of winds in the direction of these structures, the tendency of sewage to be septic from its slow velocity in a trunk line subject to solids deposition and decomposition, and the inherent tendency of the Imhoff tanks to be overloaded demand the utmost care of operation.

Many odors are prevented by scrupulous care and cleanliness of operation. The details of unit-handling explain these control measures.

In addition to the routine regulation of operation conditions, it was again found necessary to pre-chlorinate the crude sewage entering the tanks to neutralize the hydrogen sulphide odors. Chlorination was again maintained at rates of from 4 to 6 p.p.m. during such hours as odors might have been produced and carried to the nearby residences.

Cost of Operation.—It was again found possible to reduce the cost of operation of the treatment works and pumping station, despite the increased flow and the greater strength of the sewage. The 1933 net cost of operation of the Bureau of Sewage Disposal was lower than reported for the past fifteen years.

The budgetary charges for operation of the bureau during 1933 were $34,550 deducting the surplus which remained at the end of the year. Out-of-bureau services are conservatively estimated at $3,250 and salary and wage rebates amounted to $2,500. This leaves a net operating cost, chargeable to sewage treatment, of $28,800.

Of this total amount expended, $20,300 has been spent for sewage treatment and $8,500 for sewage pumping.

Cost of sewage treatment	$6.22	per	million	gals.	treated
Cost of sewage pumping	2.61	"	"	"	"
Total cost	$8.83	"	"	"	"

This represents a reduction of 20.0 per cent from the cost of treatment and pumping in 1932, a reduction of 16.8 per cent in the cost of treatment and 27.1 per cent in the cost of pumping.

The actual itemized cost of treatment, including each major phase of operation, is given in the following tabulation:

Labor	$3.87	per	m.g.	treated
Supervision, Laboratory and Control	0.63	"	"	"
Light, Power and Heat	0.26	"	"	"
Repairs	0.15	"	"	"
Supplies	0.16	"	"	"
Replacement and Purchase	0.10	"	"	"
Taxes	0.78	"	"	"
Miscellaneous	0.25	"	"	"
Total	$6.22	per	m.g.	treated

Itemized Labor Costs

Imhoff Tanks	$1.28	per	m.g.	treated
Trickling Filter	0.20	"	"	"
Control	0.12	"	"	"
Bar Rack and Screenings	0.13	"	"	"
Sludge Drying Beds	0.74	"	"	"
Night Attendance and Cleaning	0.74	"	"	"
Maintenance and Repairs	0.66	"	"	"
Total	$3.87	per	m.g.	treated

The entire subject of cost accounting is one which has troubled the sanitary engineering profession. It is difficult to compare one works with another unless consideration is given to the type of treatment, the efficiency of operation, local conditions such as labor costs and power costs, and other pertinent cost items.

The Schenectady works, for example, has an unusual tax cost of over $2,500 yearly or a charge of $0.78 per million gallons which cannot be lowered no matter how economically the treatment process is carried out. Other unusual charges are $628 for outside lights and the portion of salary appropriations which should be charged to other budgets.

Maintenance and Repairs.—A consistent program of maintenance and repairs has kept the treatment units, structures, grounds and various equipment in workable and pleasing condition.

Imhoff tank gas vents were repaired sufficiently to carry them along until the time when they will be scrapped. Gas vents have been painted; piping and valves painted and bridges and stairs kept in condition.

Sludge beds were sanded and repairs made to the bed partitions and track systems. The sludge pump was overhauled. Trickling filter nozzles were replaced and piping and gallery enclosures painted. Gallery stairs were repaired. Flow counters were repaired at intervals.

Building interiors were painted and trim decorated. Several changes were made in the laboratory and sample storage compartment. The main outfall gate was repaired.

The grounds were maintained in their usual pleasing condition, all gardening being carried out by the night operating men. All equipment was maintained in satisfactory operating condition.

Recommendations.—It is particularly gratifying to point out that the oft-repeated recommendation, as to the need for completing our sewage treatment policies, is now in line for action. It is hoped that a speedy approval of our application by the P.W.A. will give Schenectady a public works project of lasting value.

It is recommended that the sludge available in the tanks when such construction is carried out be pumped into tank trucks and hauled to the city's new golf course to be used as a fertilizer. This will save much money, will act as a splendid grass food on the sandy land and will remove this troublesome mass of solids from the tanks.

The possibility of reconstruction of our treatment works makes it necessary for the writer to repeat his recommendation that efforts be made to remove the excessive storm water inflow into our trunk sewer. This having been done, steps can be taken to intercept all portions of our sanitary sewage.

It is recommended that the underground survey made by the Bureau of Engineering be reviewed in order to determine if sufficient data are available upon which to base a study of the ultimate sanitary sewage interception needs of the city. With the new plant completed, it will be necessary for the city to make plans to pick up all the sanitary flow and deliver it to the works for treatment.

It has been estimated by the writer and the sewer division of the City Engineer's office that 60 per cent of the city's total sewage now enters the plant. An additional 30 per cent can be intercepted for some $5,000, the next 5 per cent will cost some $25,000 and the balance must be picked up gradually as certain congested sections of the city are improved. The possibility of the solution of the city's downtown storm water problems in connection with the sanitary sewerage problem has been considered and should be made the subject of a specific study.

Sewage Pumping Station

Operation.—The sewage pumping station has continued in operation during the twelve-month period except for short periods of shut-down

necessitated by flood conditions in the river. Operation efficiencies have been greater than ever recorded here, primarily because of more efficient operation of the units and the decreased unit power rates.

The station was shut down for 16 hours from March 15th to 16th, and for 57 hours from April 18th to 20th during the crest of the flood.

It was found necessary, on a few occasions of excessive rain storms, to crack the by-pass on the 36-inch interceptor entering the station in order to prevent back-flooding of the General Electric Company lines. The definite entrance of storm water into the station pits was again disclosed by the presence of leaves during the fall season.

Pumped Flow.—A total of 2,024.5 million gallons of sewage were pumped by the low-lift pumps at the station. The average daily pumpage amounted to 5.55 m.g. The maximum daily pumpage for 1933 was 6.5 m.g. on April 6th and the lowest normal pumpage amounted to 4.2 m.g.d. on July 2nd. Daily average pumpages varied from maximums of 5.9 m.g.d. in December 1932 and November 1933 to a minimum of 5.1 m.g.d. in July. It is interesting to note that the variation of 0.8 m.g.d. in monthly average pumpages is the same as the variation in treated flow at the plant.

The station continued to operate under manual control from 8 a.m. to midnight and to run automatically during the night hours, this being made possible by the uniformity and low rate of night flows.

It would be possible to make the station entirely automatic if the erratic entrance of storm water were eliminated from the sanitary sewer system. The present fluctuations of flow impose hydraulic conditions upon the station and the network of tributary interceptors which do not lend themselves to automatic operation without the use of emergency by-passes leading to the river. Such procedure would interfere with ice-cutting in the river at the present time and would not receive State approval. The economies possible with automatic operation is another argument for separation of sanitary and storm sewage as has been so often recommended.

Protective Bar Rack.—The protective bar racks in front of the large and small wet wells captured a total of 1,162 cubic feet of trash as measured in the storage cans in a compacted condition. This trash was again hauled to the treatment works and disposed of by plowing under the soil. It was found possible by adjusting the opening of the large pit inlet gates to drive much paper pulp through the racks into the pump suctions.

Two of the large well pumps have now been converted into non-clogging units by the installation of new impellers and new suction discs. These pumps have performed splendidly and have resulted in almost complete absence of clogging.

Cost of Pumpage.—It is gratifying that the cost of power for the operation of the pumps has been greatly reduced. The cost of lifting sewage per million gallons per foot of head, the true measure of pumping efficiency, has been lowered from a 1932 cost of $0.1078 to a 1933 cost of $0.0750 or a reduction of 30.4 per cent. This has been possible because of greatly reduced power rates and more efficient operation of the units.

Maintenance and Repairs.—The station was maintained in workable and neat appearance by the consistent maintenance efforts of the staff. Pumps have been kept in constant adjustment, bearings overhauled, motors adjusted and cleaned and all piping and valves kept in satisfactory condition.

The building and grounds have continued to show the results of the splendid care given them. The superstructure was painted and the roof repaired and painted. Much interior painting and decorating was carried out by the staff.

Recommendations.—It is recommended that the question of station conversion into an automatic installation be given further study in connection with the recommended study of sewage flow conditions in the sanitary lines. It has been pointed out that the sewage pumping station might serve as the center of pumping of both sanitary sewage and the storm water which now backs up in the downtown sections during high river levels. A study should be made to ascertain the feasibility of solving the joint problem.

It is highly possible that the existing station will not be adequate to handle the increases in sewage flow which will result from the sewering of all of Woodlawn and the entrance of other sections into the pumped-sewage interceptors. A complete study will be necessary to determine the best engineering practice for Schenectady to follow on its drainage and sewerage pumpage expenditures.

Difficulties were again experienced at the station pits with large quantities of oils. The congested confines of the Station make this material objectionable from a fire, asphyxiation and explosion sense. Greater cooperation between the Bureau of Sewage Disposal and the Bureau of Sewers can result in the tracing of this objectionable material to the points of entrance. The Bureau of Sewers has reported several instances of near-asphyxiation of its sewer men. The problem is serious enough to warrant study by a trained investigator.

A SYMPOSIUM ON THE ORGANIZATION, CONSTRUCTION AND OPERATION OF THE WESTCHESTER COUNTY SANITARY SEWER COMMISSION PROJECTS

By W. W. Young, Consulting Engineer of the Commission, and His Associates *

INTERURBAN SANITATION—PROMOTION, LEGISLATION, FINANCING AND ORGANIZATION

By W. W. Young

Consulting Engineer

Interurban sanitation largely concerns itself with sewerage, water supply and waste disposal. The former is most affected by topography, the latter least, but the reverse is more nearly true as to project radius. The radius of water supply projects is often over a hundred miles, that of sewers about a third of this, and of garbage scarce one third of that of sewage, though increasing with vehicular speed.

Interurban waste disposal is still so limited as scarcely to justify much discussion. When only two communities are concerned, and both the waste dump and incinerator can be suitably located on their common border, an arrangement by agreement may be satisfactory, until misunderstandings as to management or bookkeeping arise. However, to prevent such misunderstandings, especially when the waste of any community has to be conveyed through another, it is often best done by means of an act enabling it to be accomplished through the counties or states or an agency, and imposing any necessary requirements assuring some unobjectionable form of collecting, transporting and disposing of waste.

Interurban water supply, with its dams and lakes and always welcome water, is on the other hand popular at both its collecting and distributing end.

Interurban sewerage is likely to be very popular where it starts but is almost sure to be intensely unpopular wherever it pauses or stops. Unless those conceiving the project are able to contrive some solace for those on the receiving end, the project is apt to be enjoined!

It is said "Man arrives a novice on every stage of life." Seldom is this more true than when a group of communities approach, in varying degrees, a time when some form of sanitation becomes inevitable and cooperation seems to open possibilities of economy. Self interest or

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impartial government agencies may then arouse some one of them to a realization of conditions. Promotion and education may then be acceptable. The economic loss by individual action and the advantages of organization for joint relief measures may then be pointed out to all.

The promoter will then find he has to bring statistics, examples and estimates of cost to the attention of the leading men of the communities and with them approach leaders of the central government in which the communities are located. Legislative examples are frequent as in New England, New York, New Jersey and Illinois. When it can be shown to be a good investment, an enabling act can be drawn and introduced with the aid of the local member of legislature.

The history of any people can best be read in the lives of its great men. The history of how some of the sewerage problems of Westchester County were solved by its leading men may serve as an example of public spirit and cooperation.

The population of Westchester County, though small as compared to New York City, is greater than that of the District of Columbia or nine of the States and over twice as much as Wyoming and Nevada combined. Its property values exceed all other counties of the State outside of New York City, not excepting Erie County, being greater than the combined wealth of 40 upstate counties.

Sewage disposal by dilution was, as elsewhere nearby, largely taken advantage of, so that, in the early nineties, the entire interior of the county found itself hemmed by a shore front inhabited by the majority of the population of the county, which had solved, to its own satisfaction, the local sewage problems. These shore residents were naturally of the opinion that, however suitable their shore fronts and waters might be for taking care of their own sewage, the 'dumping upon them' of sewage from the larger interior areas was an unbearable outrage.

The ablest agencies of a strong, resolute and far-sighted county government were needed to overcome the inertia of such a situation and secure, to the relatively thinly populated interior districts, those opportunities for development and shore rights which are inherently theirs; though far from obviously so, in the opinion of the communities lying at the lower end of their lines of natural drainage.

The interior of the county, meanwhile, had of course been obliged to relieve the situation temporarily and a number of local disposal works, with discharges into the relatively small interior streams, were built. Small treatment plants under such conditions require liberal appropriations and exceptionally skilled and continuous management, seldom found in rapidly changing local governments. In consequence of this undermanagement, or because of undercapacity or of added sources of

pollution, the conditions of many interior streams became a menace, in a land otherwise called the ideal "Lesser Adirondacks."

The first effect of this condition was naturally felt along the most direct railroad routes, namely the Harlem road in the Bronx Valley. Here the City of New York constructed the great Kensico Dam just above White Plains, which took practically all the water out of the Bronx River, formerly used largely for sewage disposal purposes. With the diminution of the diluting water and the rapid increase of the population, this stream became an open sewer. The county representative in the Legislature introduced a bill to appoint a commission, with an appropriation to be paid out of county funds, to investigate conditions and report a remedy. It conferred with local engineers of the municipalities and secured as consulting engineer J. J. R. Croes of New York, with whom John Fairchild of Mount Vernon worked during the actual field reconnaissance.

The design as proposed was for the trunk sewer to extend through the Bronx Valley to the New York City line, and then go eastward about five miles to a point in Long Island Sound. A bill was passed in 1896 authorizing the creation of the sanitary district benefited by this sewer, and the use of the credit and moneys of the county for the construction of this sewer, until such time as its total cost was known and could be repaid to the county by taxes levied on the district. However, before becoming law, the act required the signatures of the Village President of White Plains, the Mayor of Mount Vernon, the Mayor of Yonkers and the Mayor of New York City; the latter because a small portion of the lower end of the sewer and the point of discharge itself was in New York City. The Westchester officials signed the document, but the then Mayor of New York, due, it is said, to weighty protest from various influential citizens owning land and living in the vicinity of the proposed point of discharge, refused to sign this bill and the legislation died.

The villages along the Bronx River below the dam accordingly improved the existing sewage treatment plants as far as practicable. In spite of the use of chemicals and care in operation the effluents soon created a nuisance, in summer, along the stream, already largely deprived of its natural flow for water supply use in New York City. The State Health Department was obliged to serve notice on one or more of the municipalities when the general conditions became intolerable and created an obvious public nuisance.

A preliminary bill in 1904 authorized the appointment of the three municipalities in the County principally concerned and appropriated $5,000 for making a survey of the outline for a sanitary district and an estimate for a sewer to provide the necessary sanitation facilities. Since the last legislation had been killed by including in it one municipality

whose necessity did not appear so great as the others, the new bill introduced in the legislature in 1905 not only excluded the municipality which did not sign the previous bill, but furthermore, the terms of the bill confined the sewer entirely within the limits of the one county, although this required a tunnel at great cost, three miles long, turning west instead of east near the New York City line and extending from the Bronx Valley into the Hudson Valley.

This was known as the Bronx Valley Sewer Act, Chapter 646 of the Laws of 1905. It authorized the establishment of an assessment district embracing parts of two cities and four towns, and authorized the county to pay for the sewer, it to be reimbursed later by bonds issued by the district when the total cost was known; the interest and final payment of the bonds to be borne by the district which in turn was to assess this upon each municipality, in proportion to the equalized valuation of the municipality lying within the district benefited.

This sewer was built and the assessments satisfactorily made in the manner described. The tax rate rapidly decreased in about ten years from about three dollars to about thirty cents per thousand dollars of assessed valuation.

Twenty years later, with its increasing growth, the county found itself again confronted with similar conditions; sewage from the interior of the county was creating nuisances, but this time instead of in one locality or valley, in several. This condition embarrassed recreational facilities, retarded growth, fostered nuisances, and caused the State Health Department to summon one or more of the municipalities in legal proceedings, instituted by the Attorney General. In addition, the County found itself impeding construction of sewers by construction of parkways through the valleys where sewers must of necessity be constructed. To relieve this situation, in lieu of creating a new commission, an act of legislation was passed clothing the existing Park Commission with investigatory powers similar to those of the preliminary Bronx Valley Sewer Commission of 1904.

This Commission, however, instead of reporting a bill for legislation for creating one or more single sewer districts by the state, reported in favor of an enabling act by which the county could be clothed with powers from the state to create its own sewer districts. This bill became Chapter 603 of the Laws of 1926. Under this law a commission of three men was appointed by the County Board of Supervisors to report to the supervisors the districts which in their judgment should be created, and the appropriation necessary to provide them with trunk sewers and sewage treatment plants. Amendments of this law authorized the purchase, when necessary, of existing local trunk sewer facilities and the operation of sewers and treatment plants.

Under this act the present Westchester County Sanitary Sewer Commission has provided and operates sanitary works for the Blind Brook,

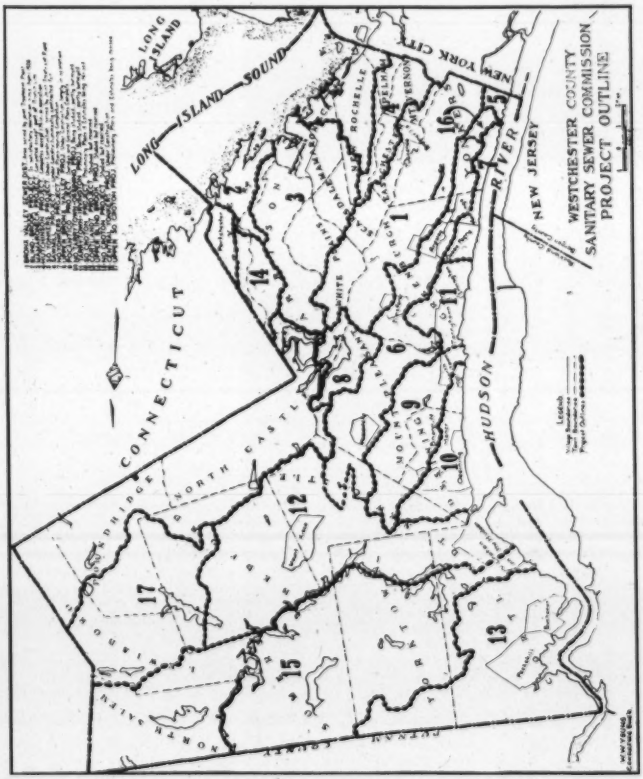

FIG. 1. Boundaries of seventeen projects of the Westchester County Sanitary Sewer Commission.

Mamaroneck, Hutchinson, South Yonkers, Central Yonkers, North Yonkers, Sawmill, and the Upper Bronx Valley Projects.

The self-contained plants, the construction of which is described by Mr. VanDenburg, remove and burn all silt and sizeable solids and

sterilize the effluent. One of these plants is located between two schools and within one hundred feet of a hospital, and another across the street from a church, bank and apartment house, hence eternal vigilance is essential.

The Westchester County system, with its nine trunk systems embracing nearly 100 miles of sewers and four plants costing over twenty-four million dollars, is one of the largest systems of its kind ever conceived at one time. Mr. Zeigler will discuss the construction work.

Although the Bronx Valley Project Trunk Sewer, some fifteen miles long, started with a diameter of forty inches and terminated between eight and ten feet, its leakage was less than an inch and a quarter flow at the outlet. Mr. Hallock will discuss the methods by which water tightness was secured.

Mr. Laverty will describe briefly the organization of the county sanitary districts and the acquisition of easements.

COUNTY SANITARY DISTRICT DETERMINATION AND SEWER EASEMENT ACQUISITION

By F. J. Laverty

Project Engineer

Two phases of the extensive sewerage program in Westchester County will be discussed; first, the determination of county sanitary districts and, second, the acquisition of sewer easements.

The population of the County of Westchester was growing rapidly in 1925. The interior and shore lines were developing and have continued to develop into very desirable suburban residential sections. A few relatively small areas in the southern part of the county, where the bulk of the population was concentrated, were more or less adequately sewered. The larger part of the county was practically without sewers. There existed a great need for a comprehensive plan for sewerage development on a county-wide basis.

The foresighted leaders of this county, bearing in mind the success of local sewerage districts such as the Sanitary District of Chicago, the Passaic Valley Sewerage District and the Metropolitan District in and near Boston, asked for and received from the New York State Legislature the passage of the Westchester County Sewer Act.

In this act, Chapter 603 of the Laws of 1926 of the State of New York, the power of fixing the area or district to be benefited by the proposed sewerage construction was delegated to the board of supervisors of Westchester County. The act, however, directed the sanitary com-

mission appointed by the supervisors to make studies, prepare preliminary plans and maps to show the areas which, in the judgment of the commission, would be served by the sewer district.

Preliminary studies of the proposed county sanitary districts were then made by the commission's engineers who used available government topographical maps, upon which the preliminary drainage areas were sketched, and which were used as a basis for reconnaissance and survey lines in the field.

The Bronx Valley Sewer District was established over twenty-five years ago. Six of the eight new districts are adjacent to the Bronx Valley and thereby had portions of their boundaries determined. The limits of the Bronx Valley Project were well monumented, and it was possible to send survey parties into the field, and with this boundary as a basis, to trace out on the ground the natural drainage limits of the other projects, and the municipal boundaries which affected the district limits. It was then possible to prepare from these surveys individual maps of the sanitary districts on a scale of 400 feet to the inch.

When these studies and maps were completed the commission held public hearings on each proposed project. On the basis of these hearings, necessary revisions were made. The plans showing the district and the proposed sewer lines, together with a report, were submitted to the Board of Supervisors by the commission with a request for the establishment of the district and an appropriation for construction. The board then held another public hearing, established the district and made the necessary appropriations for furthering the work.

At present there are nine sanitary districts in Westchester County. These are: the Bronx Valley, Hutchinson, Mamaroneck, Blind Brook, Upper Bronx, Sawmill, North Yonkers, Central Yonkers, and South Yonkers. These established districts serve about 66 per cent of the total population in the county, about 30 per cent of the area and about 65 per cent of the valuation.

The boundary lines of these nine districts have been drawn on a scale of 100 feet to the inch. These maps show in detail border lots which are wholly or in part included in the Sanitary District, and, of course, show the relation of municipal limits to the established sewer project. They also serve the purpose of a basis for assessment for local authorities when individual lots are partially in one district and partially in another, as these areas are bounded by detailed dimensions.

The determination of the sanitary districts, however, met with some difficulties. The original preliminary studies indicated that the present Mamaroneck and Blind Brook Projects should be combined. However, the Village of Rye, which comprised approximately 92 per cent of the Blind Brook area, preferred separate projects. Hence, the present di-

vision. The Mamaroneck Project also varied from natural limits, due to the inclusion within the project of the Mamaroneck Town Sewer District No. 1, which had been established for some time and included some pumped area.

In the lower part of the Sawmill Valley in Yonkers, a local trunk sewer had been constructed and the cost assessed against the local property benefited. The proposed county sewer was intended to supersede this sewer. The county reimbursed the local district for the cost of the sewer, and included this local area in the county district, thus overcoming any possible difficulties of duplicate assessments.

There are other minor variations from natural drainage limits; for example, the exclusion of remote and sparsely populated sections from their natural district and the exclusion of small marginal areas which had been provided locally with sewerage facilities in advance of the establishment of the county districts.

The inclusion or exclusion of certain areas may profoundly affect flow quantities for pipe and plant design with resultant overloading at a future date. Costs are borne by Assessment Districts and expense is never to be regarded lightly. The determination of County Sanitary Districts is, therefore, a problem of varied interests and one that requires the careful consideration of a competent engineer.

The lapse of time between the consummation of the two phases of this discussion, the determination of County Sanitary Districts and the acquisition of easements, is frequently a matter of many months. However, if the work is to progress favorably and construction is in view, easements for temporary and permanent purposes must be acquired from local property owners.

After trunk sewer lines have been located by the engineer, who has taken the factors of economy, favorable construction and the more obvious property restrictions into consideration, the location line is surveyed by local surveyors. These men have obtained this work by competitive bidding and with their knowledge of local conditions, such as monumented lines, subdivisions and municipal restrictions, make and certify to the usual property maps showing temporary and permanent easement lines cutting individual lots; the municipal lines; all property lines intersecting sewer easements; and the names of property owners and the portion of their property, in square feet, to be affected by the temporary and permanent easements. This field work of a local surveyor over a proposed sewer line was independent of the work of the Commission's engineers.

Armed with this property information and an estimate of the value of the easements as determined by local reputable appraisers, the commission's real estate representative interviewed the property owners.

Problems met in construction on owner's land were discussed and agreements reached regarding their relative value with respect to actual and consequential damages. This problem of property acquisition was sometimes a long drawn-out affair due to absence of owners, prejudice, misunderstanding or downright refusal.

It was usually possible to explain away the objections of the owners, or to make certain concessions which avoided the costs of condemnation, which had to be resorted to in only a few cases.

Some easements in public lands were secured by agreement with the municipality or the Westchester County Park Commission at no financial expense. When an agreement was reached with a private owner, an option with consent to enter upon the property was secured which permitted construction to proceed at once. Where an agreement as to the price could not be reached, an effort was made to secure an option to purchase or condemn, which also did not delay the proposed construction.

Of course, the problems which have presented themselves in the acquisition of sewer easements are many and are too varied to be considered in detail here. The chief objections which the owners have invariably raised regarding the permanent easements are three. First, the cloud on the title of the property caused by the presence of an easement on record; second, the fact that the value of the property would be depreciated by the easement, and, third, the difficulties of building over the sewer. These objections are honest and were admitted at all times by the county representatives; in answer to the first and second, the payment for the sewer easement was intended to include sufficient moneys to compensate the owner for this depreciation and loss in sale value. In reference to building over the sewer, all grants were taken with the provision that the owner could build over the sewer, provided the sewer was not subjected to any load from the structure. Several large buildings, residences and apartments have been built over the various trunk sewers, with no unfavorable results.

The permanent easement taken, which included rights to construct, operate and maintain the sewer for all time, varied in width from 12 feet to 20 feet, according to the size of the sewer to be constructed. Similarly, the temporary easement taken for the short period of construction varied from 40 feet to 60 feet in width.

Strenuous objections were made to the temporary easement. It sometimes became necessary to make settlements for trees, shrubs, etc. before it was possible to secure entrance. However, since much of the county sewer construction was in park lands and in at least three instances in private golf courses, on which construction and restorational damages were a minimum due to strict supervision by the engineer and inspector, the contractors employed by the sewer commission soon acquired a

reputation for careful work, which greatly aided in the acquisition of easements.

The real estate division of this sewer commission has been in operation since January 1930. Since that time some 313 parcels have been secured at a cost of $232,000.

In conclusion, it is pointed out that the acquisition of sewer easements, which present certain difficulties, at times may be facilitated by cooperation with local surveyors and by having as the county representatives men who understand the local property conditions as well as the engineering phases of the work.

TRUNK SEWER AND TUNNEL LOCATION, PUMPING PLANTS, SPECIFICATIONS AND CONSTRUCTION

By F. C. Zeigler

Project Engineer

This paper represents a few thoughts which would perhaps be applicable in extensive work such as that of the Westchester County Sanitary Sewer Commission.

A study should be made in advance of available maps for the determination of the areas of sewer districts to be served, of existing or prospective plans for sanitary facilities by municipalities and the general route to be followed from the upper extremity to the site of the sewage works.

Favorable topographical conditions alone may fix sewer location in a valley which of course is usually lower than any area to be served. Location elsewhere may be necessary to suit special conditions and to serve developed areas. In any case location should, if possible, be fixed at elevations low enough that connecting laterals may be able to cross below any drains, streams or other obstructions in their route to the trunk sewer without prohibitive expense.

The use of private land may be restricted by cost of easements, nuisance or other damage. The use of public land such as in parks may require avoidance of trees or other natural or artificial features which may be costly or impossible to restore. Ample working space for construction purposes in any case is of great importance. In open undeveloped country it may be necessary to make a study of its proposed future development so that location may be made to conform as far as practicable with the plans of its owners. Obstructive property owners occasionally force location to places where less objection may be encountered.

Occupation of railroad property may seem necessary or desirable but parallel use undoubtedly will be resisted by the railroad if any other practicable course lends itself to the purpose.

Manholes should be so located, if possible, to avoid water courses by a reasonable distance, especially if used for water supply purposes, so that there may be no risk of pollution.

In public streets, consideration should be given to present or future possible public or other utilities which may conflict or require expensive remedies. The removal and replacement of permanent pavements is likely to prove expensive. Excavation for sewers of even moderate depths may disturb other nearby structures particularly vital in the case of lateral sewers, water and gas mains. The importance of these and other invisible or often unknown structures which are difficult to locate, should not be under-estimated in trunk sewer location, especially where rock exists and where damage may occur from blasting in its removal.

Borings to determine subsurface materials on a preliminary route may be helpful to the engineer in further selecting one of several possible locations. They may help, if made frequently enough, in estimating partial quantities, determining ground water level, etc., also to indicate special precautions which may be necessary in construction.

Actual location of line may be so fixed or limited in developed communities that the field work simplifies itself for the engineer. Elsewhere, the matter of experience and judgment governs in balancing all of the factors.

Suitable equipment in keeping with the character of the work should be available for expediting location surveys. Previous experience in its use will be of value in careful selection of accurate, durable and most satisfactory equipment. Such details, often neglected as unimportant, if carefully thought out, may save considerable trouble, delay, uncertainty and repetition of work.

The field survey of the line should begin, if possible, at one of its extremities and be continued toward the other. If begun at the upstream end, plotting notes, and design can usually proceed in a logical, continuous and systematic order. Duplicating field books provide copies of notes for simultaneous office use. Magnetic bearings will afford a check against errors in reading and recording angles or their direction.

Precise or carefully checked levels to establish bench marks should precede ground profile levels. The benches should be placed on solid, firm and permanent objects which are reasonably close to the work but not so near as to be affected by any later construction operation. Their spacing should be such as to permit convenience in checking all intermediate level runs. Judgment should be used in selecting such points or

objects as are unlikely to be affected by frost or other elements. Hydrants, curbs and such objects are quite unsatisfactory.

In addition to notes accurately describing the location of bench marks it is advisable to attach to each one in the field a brass tag for positive identification.

Unless there is in use an otherwise established datum for the leveling system of the community, recourse should be made, if possible, to the Federal benches. Such a standard may afford the establishment, if occasion demands, of the relationship with other known leveling systems. Too many arbitrary and unknown or assumed datums are in use that are unrelated to each other or to definite planes. Reference is made to government publications such as Tidal Bench Marks of the Department of Commerce for help in use of suitable datums.

In running profile levels it is important to secure accurate elevations of such structures, clearances, etc., which may have to be considered or provided for in the proposed trunk sewer design or construction. Elevations in particular of any nearby parallel or intercepted stream should be obtained for the contract drawings and design. This may be especially important as a guide to ground water or stream conditions to be encountered in construction and to be provided for by the contractor.

Low level trunk sewers, possibly running to pumping plants, are of course a necessity where the main trunk sewer has to be so located at such an elevation as to reach by gravity an outfall some distance away. Here the required gradient with an economical pipe size and suitable velocity may fix its location far above the low areas whose sewers must be intercepted by the low level line. The problem of proper and suitable location is one in which special features may have an important bearing.

In tunnel location the condition usually arises where a natural or artificial barrier prevents economical open trenching or perhaps requires a deep siphon. In general, tunnels should be avoided if possible because of high construction cost. But topographical conditions may be such that an open trench route would be excessively long, cause damage to pavements, interfere with traffic, require costly easements, etc., all or part of which may far outweigh the cost of the short or direct line tunnel in perhaps more favorable subsurface materials.

With the tunnel determined upon as the economical proposition, various factors may govern its exact location. There may be the alternative of a short route with occupation largely in privately owned land requiring purchase and perhaps condemnation for necessary easements or a long route with occupation by irregular alignment in public land, streets, etc. The various problems must be duly considered in the presence of complete data in deciding upon the proper location of the tunnel.

One sewer tunnel in Westchester County had in its length of two miles a tangent 1.5 miles long which crossed city streets at an angle of about 45 degrees.

Due to topographical conditions, buildings, and other obstructions it was impossible to establish the sewer line on the surface of the ground by simple straight line survey methods using transit sights from either end or at intermediate points. Therefore, to establish the tunnel line on the ground for location, its direction in construction, also for property maps, profiles, working drawings and intermediate shaft location, etc., it was necessary to run six quadrilateral surveys. Each quadrilateral had two of its sides common to the adjacent one and all survey or base lines followed the public streets. The survey was made with great accuracy and slight errors that occurred were balanced in computing the traverses. Work of this sort is very trying, requires constant attention, great patience, painstaking effort and close cooperation of the entire survey party. Surveying under nearly uniform temperature conditions in the absence of sun is practically essential to the successful accomplishment of precise work required in surface location for tunnels.

Passing to the subject of pumping plants, a sewage pumping plant is obviously a necessity where the flow of low level trunk sewers or interceptors has no gravity outlet and sewage must be raised by pumping to a high level trunk sewer.

Aside from the structural features, a pumping plant and its grounds should present a pleasing exterior appearance in harmony with its surroundings and should have sufficient character to conceal, for sentimental reasons at least, as nearly as possible its purpose. Some of the essential features of a complete plant should include automatically controlled inlet gates with emergency closing device, a trash rack preferably mechanically cleaned, mechanically operated grit collection and removal, a wet well of suitable but not excessive capacity, generous capacity in electric motor-driven pumps of the non-clogging sewage type with enough units for emergency and breakdown reserve, automatically controlled as to single or multiple operation, and suitable electrical equipment including switchboard, transformers and meters. Of vital importance in a modern electrically operated plant is a provision for two sources of power so that in case one source fails there will be only a momentary plant shutdown in switching to the other source.

Purchased power from a main feeder with a second main feeder in reserve should be the minimum requirement as insurance against plant shutdown. Serious damage caused by complete shutdown of the plant during possible failure of all purchased power is a risk which calls for a separate power service easily provided for by Diesel engines to generate current at the switchboard. A modern plant should be a self-contained,

largely automatic installation requiring a minimum amount of manual attention.

The design of important sewage pumping plants is highly involved in hydraulic, electrical, mechanical and other features requiring dependability at all times. Among important considerations may be mentioned a few such as deciding the least number and size of pump units to be installed with safety, the desirability of using primary power motors to reduce transformer losses, relation of maximum demand power charge to motor horsepower and service, uniformity in pumped flow to treatment plant, size of force main and capacity of venturi meter, sump

FIG. 1.—Hutchinson Pumping Plant.

pumps, emergency storage battery lighting and miscellaneous auxiliary equipment, tools, facilities, etc.

The switchboard for a pumping plant is likely to be far more complex than required in any other sewage works operation. All of the functions of the switchboard and its auxiliary telltale board should be carefully worked out and installed by specialists in this field of work. Stock types of electrical controls, devices, etc. are rarely suitable to pumping plant installations without attendant risk of failure to function as desired.

Specifications vary greatly and often reflect the knowledge and experience of their authors in the technical, practical, equitable and legal matters which are usually involved.

In municipal contracts for sewers and appurtenant structures one form of contract includes an advertisement, invitation to contractors, specifications, forms for contractor's bid, contract and bond.

The purport of the contract, needless to say, is to cover the scope of the work, its location, prescribed materials, the results to be attained, contractor's experience, financial competence, his bid, and such contractual provisions as necessary for obtaining materials and workmanship called for and affording ample protection to the municipality against claims for damages of any kind arising out of the work. The old practice of writing contracts loosely in generalities and vagueness has given way to a new order of clarity in specifying requirements, and contractual provisions. Close competition has brought a realization to contractors of the need of self protection under the rights which may be afforded by the clauses of a contract. Especial care should be taken to include every anticipated condition which may arise in the work if extras and claims are to be avoided. Fairness to the contractor should not be overlooked. The legality of various provisions should be verified by consultation with attorneys experienced in contract work. Observance of labor, lien and other laws and ordinances should be required.

Among the provisions which should receive particular attention in drafting sewer and appurtenant specifications may be mentioned a few such as a requirement that certified bidding checks of another state shall bear the certification of a correspondent bank in the state where the work is to be done; caution in any use of boring information preferably prohibiting such to contractors; a clear statement as to approximation of quantities, compensation, property damage and public liability insurance with such "save harmless" provisions as will afford ample protection to all concerned; extra work clauses stating inclusions and exclusions; guarantees and trial operation of plant and equipment by the contractor for a given length of time; maintenance for a definite time after completion prior to final payment; preference for local labor and minimum legal wage rates; permits, bonds, observance of local ordinances, regulations, etc., maximum infiltration or leakage allowance; concrete, its graded aggregates and proportions to obtain greatest strength; material bonds and other provisions to protect the municipality in the case of obligations incurred by the contractor for which it might be held legally responsible when payments otherwise due the contractor become liened or assigned. Unless protected with satisfactory evidence in the form of receipted bills it is somewhat risky to make allowance as sometimes done in the past in partial payment estimates for certain materials delivered at the site of the work which might be subject to liens.

In construction it is essential that the field engineers and inspectors be thoroughly familiar with the provisions of the specifications. Accurate field data and profiles bearing on the work and all records affecting payments are essential. Experienced contractors naturally handle their work with skill and speed, especially in sewer construction. Lack of experience usually results in losses due to inability to overcome seemingly great obstacles. One of the most important of troubles to be encountered in sewer and appurtenant construction is the proper control of subsurface water conditions; also the proper handling of materials to be excavated to secure a firm undisturbed subgrade without loss or shifting of adjacent ground. The construction of large and deep trunk sewers usually involves far greater difficulties than small ones, yet the skilled sewer contractor appears to manage both with ease.

Tight and substantial trench sheeting, firmly braced, driven well below subgrade in a workmanlike manner with air hammers, backfilling of cavities outside of the sheeting, storing excavated material far enough away from the edge of the trench to avoid surcharge pressure are necessary, of course, in difficult or deep ground conditions, especially where adjacent to pavements, buildings, tracks or other structures.

Soft trench bottoms may often be made firm by removing some or all of the poor subgrade material and replacing it with broken stone, gravel or tamped cinders. In boiling, water-laden, shifting materials, a mat of hay placed in the bottom before the broken stone will usually be effective in eliminating troublesome conditions. Good pumps of the centrifugal type operating from deep sumps to which the underdrain is led, placed at reasonably close intervals, are most commonly used for trench drainage. When necessary to avoid deposits or turbidity in streams or drains, the well point system in favorable soils will usually be more satisfactory than pumps. However, pumping into properly designed and maintained settling boxes with suitable overflows may otherwise reduce objectionable deposits.

Crawler pull shovels and convertible cranes with clam-shell buckets for trench excavating and drag line buckets and bulldozers for backfilling in the presence of puddling are commonly used on large sewer work.

The circular type sewer where of reinforced concrete may be of monolithic construction or pre-cast pipe laid on a poured concrete cradle. Some contractors seem to be of the opinion that monolithic work is less costly than the pre-cast type. The majority appear in favor of pre-cast pipe construction if for no other advantage than speed in laying. Joint making, however, requires skilled and experienced workmen if trouble is to be avoided in testing or otherwise.

Tunnel construction requires expert planning and execution. Size of the tunnel and character of material encountered greatly affect the methods to be used and the ultimate cost. In small tunnels practically all work must be done by hand. Larger tunnels permit use of track and machinery. Rock work with its blasting often involves risk of damage to buildings and other property. In cities blasting may be restricted by ordinance to daytime working hours so that progress may be slow and expensive. Tunneling in soft or flowing and shifting material may require perhaps the use of compressed air for its successful execution. The use of steel liner plates is usually very satisfactory for temporarily restraining soft or non self-supporting material in tunnel excavation. Where heavy or moving loads are overhead these lines have been reinforced with alternating steel I-beam ribs.

Tunnel portals and shafts with their equipment and noisy operation are often a nuisance over an extended period of time and a source of many complaints in a populated community. Under such conditions the use of silent equipment and reduction of all noise to a minimum is necessary.

Suitable headframes, cages, cars, trucks, hoisting and material handling equipment are essential to economical prosecution of the work. Facilities for good ventilation and drainage should be provided as well as good electric lighting. These three are especially important to the engineer in his line and grade work. In short tunnels electric lights may be supplied by means of portable generators.

Alignment holes may be driven vertically from the surface of the ground to the tunnel level at convenient places for establishing or checking line and grade in long tunnels or ones of irregular alignment.

Jacking pre-cast concrete pipes in material other than rock under roads and railroads is somewhat successful under suitable conditions. Favorable use of the jacking process usually occurs with small diameter pipe and through short distances.

Among the essentials which are necessary to success in jacking pipe may be mentioned a few such as careful planning and preparation of all details of the work, definite advance information as to subsurface soil conditions at pipe grade, use of extra strength reinforced concrete pipe of the A. S. T. M. Designation C76–30T, usually 4750 lb. quality, absolute drainage of water to a level below grade, dependable jacks, in duplicate, of ample power, tested in advance, experienced workmen and superintendent, as well as complete equipment necessary for continuous operation. With large pipes the use of a steel shield, a part of which controls its direction by means of screws, at the advance end of the work appears to have been the most successful method used to maintain true line and grade throughout the jacking operation.

Pipes which are jacked may be used to envelope a smaller enclosed pipe sewer. Otherwise if used for the sewer itself special attention should be used to tightly seal all joints as well as to grout them to prevent infiltration or leakage.

Concrete for lining tunnels of small diameter may be deposited by hand or placed by chuting through bore holes previously driven from the ground surface. In larger tunnels rapid progress may be made by conveying the concrete in cars from a shaft or portal mixing plant to a chuting machine set up on a movable carriage just outside of the forms to be concreted. The central mixing plant so arranged as to reduce to a minimum the handling of materials and with features permitting close regulation and uniformity of ouput lends itself to most satisfactory and economical work. Transit mixed concrete properly controlled and inspected at all stages is an excellent product provided it can be delivered as and when desired without delay. In fact, care in designing concrete by analyzing and selection of materials and their proportioning will produce very gratifying results in strength and quality.

WATER TIGHTNESS IN SEWERS AND HOW TO SECURE IT

By E. C. Hallock

Chief Inspector

The importance of building watertight sewers is easily understood when it is realized that the cost of operating treatment plants depends, to a large degree, upon the amount of sewage treated, and its useful life is limited by its capacity. The infiltration of ground water and its resultant treatment at the plants, therefore, constitutes an unnecessary expense and reduces the capacity of the plant for treating actual sewage.

Far more important from a public health standpoint is the safeguarding of public water supplies from sewer leakage. This had to be taken into consideration where the sewer crossed water aqueducts or was laid in the vicinity of water supplies and, in one instance, passed under a lake or reservoir used for drinking water.

Since the trunk lines, for the most part, follow along valleys also traversed by rivers which the sewers cross at several points, sometimes crossing from three to five feet below the river bed, and as the lines are nearly all far below ground water level, the utmost care was taken to insure a permanent and tight line and to prevent seepage into the sewer.

On the work of the Westchester County Sanitary Commission it has been necessary to use both cast iron pipe and reinforced concrete pipe. On cast iron pipe, which was of the bell and spigot type, the most com-

monly used joint was made by the usual method of first forcing in the oakum to prevent the lead that is later poured in from entering the pipe, the lead then poured and caulked into the bell. Twelve foot lengths of pipe are used, laid on crushed stone with a vitrified tile underdrain which is a great aid in securing a dry trench and the dry pipe necessary for a successful joint.

On the sewer outfall lines, which are of various sizes, the largest being of 54 in. cast iron pipe, with machined lips on both ends, the Victaulic joint was used. This is a flexible joint consisting of a rubber gasket over the lips, held in place by segmented steel rings bolted together.

In one instance where a large cast iron pipe was supported over a stream the Dresser Coupling was used. Only in the treatment plants proper have any flange joints been used.

The Commission specifications require that a water or air pressure test of at least 40 pounds per square inch shall be applied for 24 hours to the interior of cast iron gravity or pressure sewers and all joints which leak under such test shall be recaulked or otherwise repaired even to the extent of melting the joint out and repouring and caulking until tight. In making the water test the trench and bell holes shall be kept free of water.

On this work many miles of reinforced pre-cast concrete pipe have been laid. This pipe ranges in size from 24 in. to 72 in. in diameter. Eight-foot lengths are generally used. The general method for making these joints is first to break out a piece from the top of the bell to provide for pouring in the mortar. The pipe is then laid in the trench on pre-cast concrete blocks about 1 ft. wide which have been brought to grade and a piece of burlap about 8 inches wide is wrapped around the joint and made tight on top, leaving room to pour (Fig. 1). A concrete cradle for the pipe is then poured, using a mix of 1:1⅝:3¼, crushed stone of ¾ in. being used and two 1-in. reinforcing rods, one on each side. After this the joint is mortared up on the inside and the following day the outside of the joint is poured. Another method is to use a steel sealing band which is expanded on the inside, and then the joint is poured from the outside as above.

The mortar generally used in these joints consists of a 1:1 or 1:1½ mix, the sand passing a 1/16 in. mesh. Quick setting cement is used in fall and winter and ordinary cement in spring and summer. To keep an even temperature tar paper is placed on whalers, leaving an air space underneath.

A joint which was developed and patented by one of our inspectors and named after him, called the Burtnett Joint, has undergone successfully some pretty severe tests. This consists of a special bituminous

compound mixed with equal portions of cement and sand and is used in connection with a special groove in the joint.

The Commission's specifications for testing reinforced concrete pipe for watertightness provide that "The sewer barrel shall be filled with water which shall then be brought to a pressure equivalent to a height, upon completion of the test, of no less than 4 feet above the exterior crown of the sewer at the upstream end of each section tested. When making a test with water inside of the sewer, all water shall be excluded from the trench.

"Leakage from inside or infiltration from outside the concrete pipe sewer during a continuous 24-hour test shall not exceed a rate of 1 gallon

FIG. 1. Joint on pre-cast concrete pipe.

per hour per inch of inner diameter of pipe per 100 feet of completed sewer, and no joint or 8-foot length of pipe in completed sewer shall leak an amount in excess of 1 quart per hour per inch of inner diameter."

The success of any type of joint depends upon the proper execution of the prescribed method. The contractors have worked with the inspectors watching these joints and in nearly all cases have secured finished sewers which in tests always showed an amount of leakage far below the amount allowed by the specifications. In the case of the Mamaroneck trunk line sewers the total infiltration allowed was over 725,000 gallons for 24 hours, for about 15 miles, while the actual infiltration showed a maximum of 86,000 gallons for 24 hours.

FINE SCREENING, INCINERATION AND STERILIZATION PLANT CONSTRUCTION AND FEATURES

By J. W. VanDenburg

Project Engineer

Each of the three plants of the Westchester County Sanitary Sewer Commission at South Yonkers, Mamaroneck and North Yonkers cost, without land, between $500,000 and $1,000,000. They provide for fine screening and chlorination, with incineration of the removed solids. The effluent in each case is discharged under 40 feet or more of swift tidal water. The capacities run from 40 to 80 million gallons. The South Yonkers and the Mamaroneck plants have been in operation about two and a half years, and the Sawmill about half a year, the latter being not yet entirely completed. The tributary areas have not all been connected

Fig. 1.—Bronx, Hutchinson and South Yonkers Plant.

and the present flows are increasing as connections are made. As is usual, some conditions met have required solutions which are more or less particular to the plants, and it is some of these which will be touched on.

The three plants offer striking contrasts in foundation requirements. The South Yonkers Plant sets on a stratum of brown sand overlying bed rock, which varies from a few feet on one side to a considerable depth on

FIG. 2.—Mamaroneck Plant.

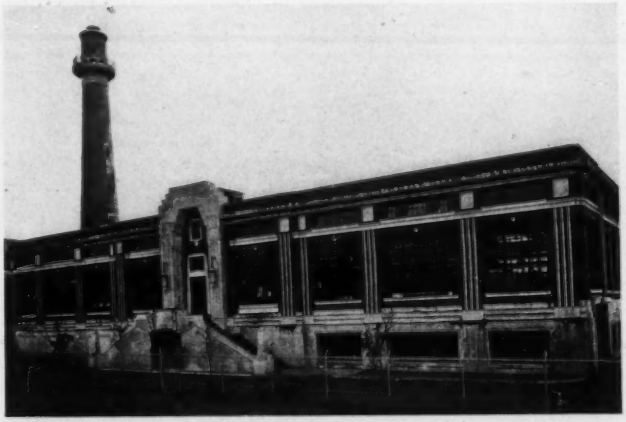

FIG. 3.—Sawmill, North and Central/Yonkers Plant.

the other. There is just enough clay in the sand to make it stand for quite a time on the side of a 10 or 15 foot cut. Footings were studied to be kept above ground water and this was found to be possible everywhere but in the incinerator pit. This resulted in spread footings without further support. The unit loads were kept low and the results have been very satisfactory with a considerable saving in cost. At Mamaroneck, however, where a pump well to pick up low level drainage was necessary, this part of the structure went down some 30 feet into bed rock. The rest of the building foundation was from 10 to 20 feet above the rock surface, and in order to secure a uniform support, concrete piles were driven firmly to rock. The results here have also been excellent and the possibility of part of the building subsiding with the rest remaining rigid has been avoided. At the Sawmill Plant borings showed rock to be from 80 to 100 feet down, overlaid with a considerable layer of sand and gravel and above that a heavy layer of soft blue-black river mud, covered by a few feet of recent miscellaneous fill. As the upper ends of piles were in the range of the top of ground water or above, composite piles were used, driven solidly into the sand and gravel stratum, care being taken to go through a thin layer of peat which developed near the top of the sand in some places. Some of the piles had an overall length below cutoff of over 90 feet. Though the ground was so soft that it could be felt to quake all around the driving rig when in operation, the results appear entirely satisfactory.

The type of building structures used results in considerable expanses of flat roof, and in accordance with the trend of the times air markings complying with the Government regulations, have been painted on them.

Another feature, having to do with the field work particularly, was the use of various parts of the installations before completion of the entire plant. At two of the plants screening was commenced months before completion of the entire job, in one case before the roof was up. Similarly, the installation of the chlorination apparatus was arranged so that use could be made of it long before other parts of the plants were done.

This idea was followed particularly at the Sawmill Plant with the coordinating of the incoming and outgoing sewer lines. Two sections of the incoming lines were ready and put to use, though not complete in every detail, within a few days of the commencement of screening and chlorinating. In systems involving such large expenditures, and in which it is particularly important that their facilities be available during the summer, the advantage of such procedures is evident.

Returning to details of the plants themselves, as a thought on piping, the general plan has been followed in these plants to place all piping in an accessible position, avoiding, as far as possible, encasement in masonry

or under floors. While this may not always provide the most attractive result for appearance, it is a blessing when trouble occurs.

As a list of the piping in these particular plants includes cold fresh water, hot water, salt water, roof drains, station toilets, floor drains, oil piping, chlorine gas piping, chlorine solution piping, steam heating piping, return heating piping, compressed air piping as well as some half dozen assorted pipings for special instrument installations, it becomes evident that the purpose of a pipe may not be at once clear from a casual glance. To aid in tracing lines, the well known method of distinctive coloring has been used.

FIG. 4.—Screen Room. South Yonkers Plant.

The same method of installing electric conduits has been followed as for pipe, namely to keep them out of the walls and floors as much as possible. Many no doubt prefer conduits concreted into floor slabs, and there are some places where motors cannot be reached in other ways without entailing considerable inconvenience, but it is remarkable how much of the conduit work can be kept visible by a little planning, and how readily lines can be followed and changes made when such an arrangement is used.

Among the pipe lines, the chlorine solution lines are, from the very corrosive nature of the fluid they carry, a somewhat troublesome problem. While vitrified material is well fitted to resist this action, the effective

jointing of the separate lengths of vitrified pipe is difficult and the pipes themselves somewhat brittle. Of other materials, hard rubber is promising and steel pipe lined with hard rubber has been used in two of the plants. It seems to be standing up well and is rugged enough to permit installation in an exposed position where it can be easily installed and constantly watched. Fortunately, it has developed that good workmanship has resulted in no difficulties to date. The final length of its life is not yet known. The cost is about double that of wrought iron pipe but, of course, the iron pipe would not be serviceable. There are several other little points about this chlorine solution piping that have come up.

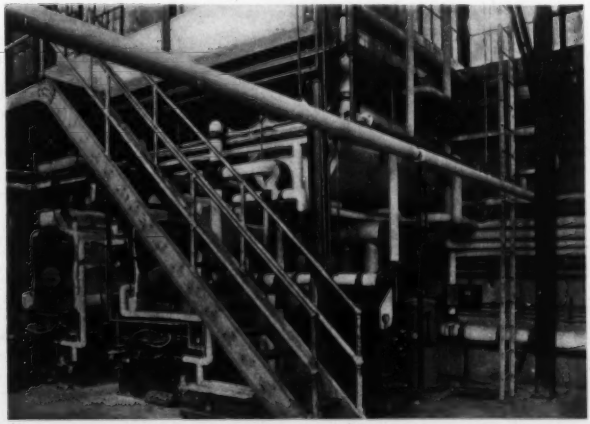

FIG. 5.—Typical Piping. Sawmill Plant.

The question of valves which will not stick and are able to stand the service, has been met in the smaller sizes by screw-down valves made completely of hard rubber. They are of somewhat different design from ordinary gate or globe valves, more nearly resembling the latter, and came to our attention at one of the annual chemical shows in New York.

An interesting economy in the water for chlorination has been found to result from a reduction of the pressure in the chlorine solution lines. Even with a steady downward grade there seems to be a tendency for air to pocket in the high end and some back pressure to occur. By drawing off this air and thus filling the lines the resistance is reduced and a saving in one case of more than a third of the water consumption resulted. Whether water is purchased or pumped, this is apt to be worth while.

Keeping the screens clean is quite a job and requires quite a little water. Common procedure is hosing down, dripping on a little kerosene, and rubbing up from time to time. At the Sawmill Plant there has been provided an adaptation of the reciprocating sprinkler used to water large gardens. This automatically oscillates back and forth in such a way as to direct a stream of water against the screen plates as they revolve and is quite an effective aid in keeping them clean.

The water used for this purpose is from a centrifugal pump at a pressure of about 50 lb. per sq. in., which gives quite a nozzle velocity. The pump is set in the plant with its suction in the river. Being of the

FIG. 6.—Chlorine Machine Room. Sawmill Plant.

self-priming type, it is very unlikely to lose its suction, and being centrifugal the power decreases as the demand for water drops.

To this source of water are connected, also, the injectors of the chlorine machines, as it has been found much cheaper to use this salt water than the very excellent water from Westchester's lakes passing by on its way to New York City. Fluctuations in pressure due to the use of river water for washing down, etc., are kept out of the machines by the pressure regulating valves. It has been considered advisable to use fresh water for the trays, but as this is only about a tenth of the total, the saving on the balance is well worth while.

A reduction of odors in the plants has been found to be aided by—first, an application of a few parts per million of chlorine to the sewage

just before it enters the plant; and, second, keeping the gates at the incoming point closed down so they touch the surface of the flow. At South Yonkers the point of application is, in fact, downstream from the gates and good results are attained, but a location farther upstream seems more desirable from this point of view. Another aid in keeping odors in the plant under control is a connection between the bins, especially the screenings storage bin over the incinerator, to a negative pressure occasioned either by a fan or by the incinerator. At the Sawmill Plant the arrangement is such that this draft also pulls through the roll press housing, thus tending to prevent odors from this source. With care in arrangement and use, a comparatively small suction line can draw from quite a large area.

Still another aid, and one of the most important, is curving the channels so that corners where settlement might occur, are avoided as much as possible. To assist in this, the sluice gates controlling the flow at various points have been provided with a semicircular shape at the bottom instead of the conventional rectangular outline and a similar cross section given to the waterways.

The Venturi meters, of which there is one at the Mamaroneck Plant with a large diameter of 54 in. and one at the Sawmill Plant with a diameter of 48 in., are of the type having an eccentric throat, so as to effect a level invert, instead of the usual shape symmetrical about a longitudinal axis, thus avoiding any tendency for accumulations at the upstream side of the hump which the latter type would occasion in the invert.

To aid in sampling the effluent, sampling pumps have been installed with their suctions in the effluent lines near the Venturis, having a take-off in the laboratory. These pumps are so hooked up with cross connections on the suction and discharge, that they can also be used as sump pumps for low places in the plants, such as the Venturi chamber.

Two types of incinerators, both adaptations of well known standard makes, have been used, one with a water jacketed fire box and one with fire brick construction throughout. Both have met the somewhat stringent specifications and the guaranteed performance.

The problem of auxiliaries to the incinerators is an interesting one. While the precise amount of oil burned per ton is, of course, important, it is evident that this is only one of the items entering into the total cost of burning, and that the largest single economy is perhaps to be looked for in reducing the actual time of burning with a given setup of apparatus. With this in mind an effort has been made to reduce the water content of the screenings before putting them in the incinerator, and it has been found possible to better than cut the overall weight in half.

This result, added to the fact that the drier screenings burn more readily and require less fuel, makes the advantage of such a procedure evident.

The matter of charging the incinerators is more complicated than might at first appear. If the screenings are sent direct from the screens to the bin over the incinerator, the water content is high, averaging probably over 90 per cent. Some of this water accumulates in the bottom of the bin and may come through with the first charge. This means a sloppy job for the fireman and a slowing up of the burning, as a full charge cannot be put in and the water is slow in vaporizing. On the other hand, if the drier screenings from the roll press are permitted to stand for a while in the bins, they pack down and have to be dislodged, especially the accumulation just above the gates. This is accomplished either by an air jet manipulated from above the top of the bin, or by air jets inside the bin. In the Sawmill Plant an arrangement of air jets rigged so they can be rotated inside the bin from the stoking floor is being put into operation.

The problem of reducing the water content of the screenings has been attacked by the simple method of passing them under a roller on a belt. The necessary mechanical details are provided to effect the driving and adjust the pressure, and more than half the water is removed.

The problem of the feeding of the material from a bin to the belt has actually been a more difficult question than the operation of the roll press itself, and the method finally adopted at the Sawmill Plant has been a positive rotary feeder, which has proved quite effective.

To assist in control of the plant, instrument boards have been provided in two of them. These carry indicators, showing water level, temperature and rate of flow, and other similar pieces of equipment and have another space where small pilot lights show what pieces of the main equipment are in use, such as screens, pumps, etc. An item in connection with these is the use of a small 1-watt neon bulb. The light is not bright, but is very plain, and a test bulb which was put into use to check up on the claim of an 800 hour life is still burning after 7,000 hours, so replacement should be infrequent, especially when compared to the usual incandescent bulbs.

So many excellent recording and indicating devices are now manufactured that it is possible to keep track readily of a large number of diverse operations, and smoke, or rather its absence from the incinerating process to which the sewage solids are subjected, is of extreme importance. While few people perhaps are surprised when they read that aside from some four tastes, all tasting depends on the sense of smell, it is still somewhat astonishing to observe how much smelling is dependent on the sense of sight. The idea offers food for thought, and it is important to relieve the communities of objectionable odors due to

seeing smoke rising from the incinerator chimneys. Therefore, at the Sawmill Plant a smoke indicator was installed which operates to light in series five electrical lamps, if the density of the flue gasses should increase, by directing the gas across a ray from an incandescent bulb to an electric coil. These lights may be adjusted to show even before smoke is visible at the top of the stack, and being placed at the stoking floor are a very convenient and accurate guide in the operation of the fire, and assist in assuring satisfactory performance of the plant as a whole.

Industrial Wastes

ACTIVATED SLUDGE FOR DAIRY WASTE*

By H. Kessener and Willem Rudolfs

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It has been frequently stated that it is practically impossible to treat dairy wastes by the activated sludge process. This would be true if quantities of milk-sugars were discharged. The growth of undesirable organisms would prevent efficient operation and the organic acids produced impair the activities of the desirable organisms. To show that the activated sludge process can be successfully used, producing a highly purified effluent without difficulties and at relatively low costs, is the purpose of this article.

Experimental

The senior writer made the first laboratory experiments in 1921 on purifying dairy wastes by the activated sludge process, using compressed air. These experiments established definitely the possibility of clarifying and stabilizing dairy wastes by this process. Subsequently more experiments were conducted, both in the laboratory and on a plant-scale basis in 1922 and 1923. For the experiments conducted on a working scale a Bolton tank (Simplex system) was used. The difficulties encountered were principally those classified under the heading of "bulking." Continued experiments showed that no bulking occurred when the Haworth system of aeration was used.

During 1924 extensive comparative experiments were made on dairy wastes at Vorden, Holland. The following table shows the systems used, the types of wastes treated, tank capacities, air and power requirements:

System	Waste Treated	Tank Capacity	Air, Cu. Ft./ Cu. Ft. Waste	K.W.H./ Cu. Ft. Waste
A. Direct Air...	Crudge Limed Dairy	388 Cu. Ft.	7.2	8.2
B. Direct Air...	Effl. Septic Tank, Dairy	388 Cu. Ft.	3.6	4.1
C. Simplex.....	Crude Limed Dairy	154 Cu. Ft.	—	0.095

*Journal Series Paper, New Jersey Agricultural Experiment Station, New Brunswick, N. J., Dept. Water & Sewage Research.

From 1924 to 1927 extensive studies were made on the development of a surface aeration scheme which would distribute finely divided bubbles of air into the sewage and wastes, and cause a strong rippling effect on the surface in addition to some fine spray. The result was a device creating an accelerated mountain-stream aeration effect by the use of brushes similar to those used in certain street cleaning devices. Brush-aeration plants were built for slaughterhouse waste in Apeldoorn, Beverwijk, Helmond, Zwolle, and Zaandam, Holland, and for sewage aeration at Knocke, Belgium. Several others have been built since in different countries, namely Germany, France, Belgium and one in New Jersey, U. S. A.

In 1929, the senior author, together with Dr. H. Bach of the Emschergenossenschaft in Germany, designed a plant for a condensed milk factory of the Nestlé Company at Boué, France. This plant handles about 90,000 quarts of milk a day in summer and was placed in operation in October, 1930. It has been working very satisfactorily.

In 1931, Kessener designed a plant for the Nestlé dairy works at Hamoir, Belgium, for a capacity of about 25,000 quarts of milk per day. It was placed in operation during the spring of 1932 and visited by the junior author in September, 1933.

At both plants lime is added to the waste during the summer months to prevent too rapid acidification. It is planned to omit liming next summer at Hamoir since this plant produces considerable volumes of cooling water, which will be used for diluting the waste to prevent acid fermentation.

Hamoir Dairy Waste Treatment

This branch of dairy works of the Nestlé (Swiss) concern is located in the beautiful Ourthe River valley, about 60 miles from Liège. At the beginning of the World War the German armies marched through this valley in the direction of industrial Liège for their first major attack. The most important industries in this section of the valley are stone quarries, dairies and summer resorts. As a summer resort the Ourthe Valley is well known to those living in Western Europe. The river is a rapidly flowing, shallow mountain stream supporting a variety of fish, among which trout is in abundance.

The Nestlé industry is operated for a period of 8 hours daily, while the waste is treated for 24 hours. The products are condensed milk, sweetened condensed milk, some butter and cheese.

Description of Plant

The essential units of the treatment plant consist of a mixing tank, primary settling tank, aeration tank, final settling tank and separate

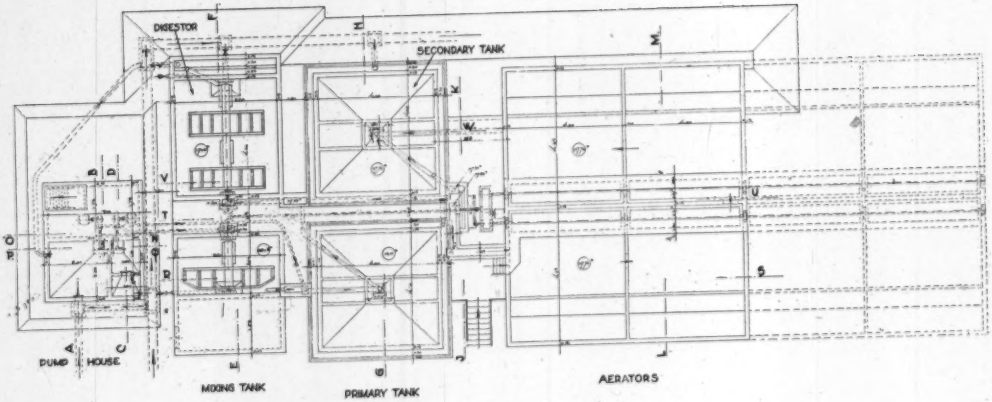

FIG. 1. Plans of plant for dairy waste treatment at Hamoir, Belgium. Hamoir.

sludge digestion tank. The layout of the plant is shown in Fig. 1, while the details are shown in Figures 2, 3, and 4.

Perhaps the outstanding feature of the plant is its simplicity. The waste enters the mixing tank where, during the summer, about 40 lb. of hydrated lime is added daily; no liming is applied during the winter. The lime-treated waste is settled in the primary tank, after which the

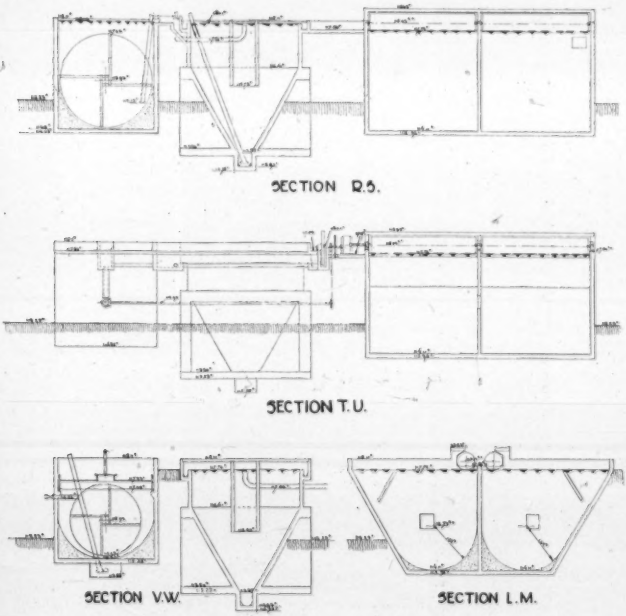

FIG. 2. Sections of mixing tank, primary tank and aerators, dairy waste treatment, Hamoir.

sewage is aerated by brushes and re-settled. The mixture of primary sludge and surplus activated sludge is conveyed by gravity flow to the digester. The volume of return activated sludge is regulated automatically by a telescopic valve. Sludge is pumped back by a water wheel, which is driven by the same motor that operates the brushes.

Dortmund type (hopper-bottom) settling tanks are used. The settled limed sludge from the primary settling tank flows directly into the di-

gester. The lime added aids reaction control in the digester. This is rather important with the milk waste treated. No additional lime is needed. The digester contains a wooden stirring device for the prevention of scum formation and mixing of fresh solids with ripe material. The wooden racks rotate for 5 minutes after each addition of sludge.

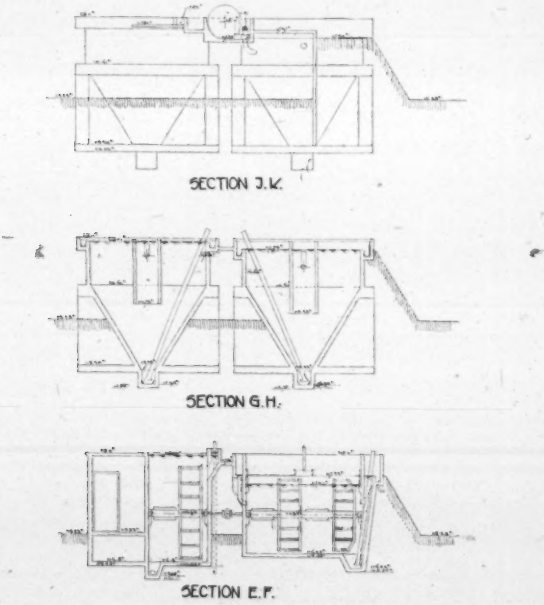

FIG. 3. Section of sludge return, brush aerator, secondary tanks, mixing and digestion tanks, Hamoir.

Aeration is accomplished by specially made street brushes (Fig. 5) which rotate at 65 to 70 rev. per minute. The total length of the brushes is 52 feet, the diameter 26 inches. They dip about 0.6 inch into the liquid. The factory works only 8 hours per day, but the brushes are kept in operation continuously. A 4½ H.P. motor is used for driving the brushes, agitators and waterwheel. This motor uses 2.5 KWH per hour. The brushes spray a portion of the sewage into the air and cause

an intense rippling effect of the mixed liquor across the tank. No additional stirring equipment is necessary to prevent the solids from settling at the bottom of the tank. In earlier plants submerged paddle wheels

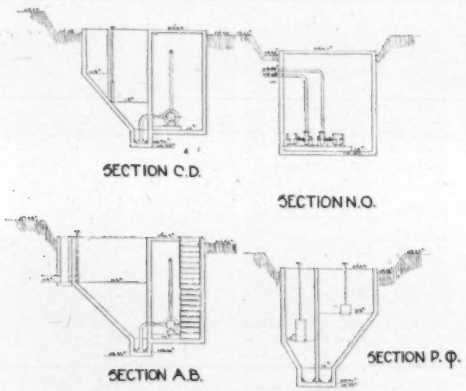

FIG. 4. Sections of sump, pumphouse, and location of gate valves, dairy waste treatment, Hamoir.

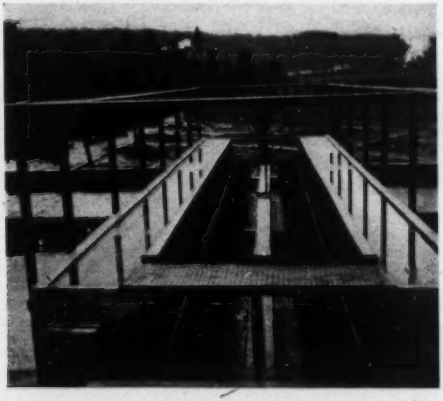

FIG. 5. View of brushes used for aeration at Hamoir.

had been installed for precaution. It developed later that the paddle wheels were unnecessary.

The effect of the brushes on the surface movement of the liquid is shown in Fig. 6, while a close-up view of the spray caused by the brushes

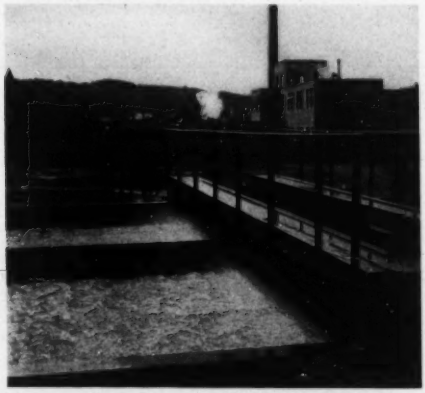

FIG. 6. Surface movement of liquid caused by brushes, factory in background.

FIG. 7. Close-up view of spray caused by brushes, dairy waste treatment, Hamoir.

is shown in Fig. 7. The spray is about 2 feet high and extends about half way across the tank.

The plant was constructed to handle the wastes from the treatment of 25,000 liters of milk per day, but the settling tanks are large enough

to allow double the capacity. For extension only an additional aeration tank is necessary, without further alterations.

The cost of construction was rather low. Cost for concrete was about $4,000, for a 52 ft. brush, waterwheel and agitator in digestion tank about $700, and about $250 for reduction gear, bearings, shaft, etc.

Operation

During the time of the visit of the junior author, the plant had been in operation about 1½ years. It was exceedingly clean, neat and attractive in appearance and was operated by one laborer. Sludge was discharged to the digester and the supernatant liquor, which was returned to the influent, was very clear with a slight H_2S odor. The junior writer made some settling tests during his visit, the results of which are shown in Fig. 8. Mixtures were taken near the entrance and near the end of

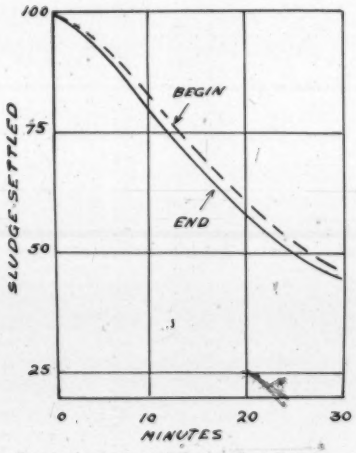

Fig. 8. Curves showing settling of activated sludge at Hamoir.

the aeration tank. It appears that the sludge was rather slow in settling and was voluminous after 30 minutes. Results of analyses taken at random, including those of samples taken during the visit, are given in Table I. The results indicate that the settled waste has a low average suspended solids content and an average 5-day B.O.D. of over 300 p.p.m. so that most of the putrescible material is in a soluble form. The effluent

TABLE I.—*Treatment of Dairy Waste at Hamoir, Belgium*

Results of Analyses Made During 1932 and 1933 on Influent to Aerator and Final Effluent.

Date	5/28/32		6/6	6/13		6/25			11/12		1/21/33			3/3	3/17	7/12	9/5	Average	
	I	E	E	I	E	I	E	River	I	E	E	E	E	E	E	E	E	I	E
Ox. Consumed (4 Hr.) P.P.M.	121	5	2	48	4	85	3	1	60	2	—	—	2	5	—	3	4	79	3
$KMnO_4$ as O_2	235	10	6	197	8	302	6	2	107	5	12	15	3	11	11	6	9	210	8.5
B.O.D. P.P.M. 2 Days	225	—	—	75	—	—	—	—	256	—	—	—	—	—	—	—	—	185	—
5 "	342	5	4	173	6	396	5	3	344	6	—	—	1	7	6	8	5	314	5.3
20 "	456	—	—	252	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N_2O_3 P.P.M.	—	tr.	tr.	—	0.02	—	tr.	0.17	—	tr.	tr.	tr.	tr.	tr.	tr.	tr.	0	—	tr.
N_2O_5 "	—	5.7	11	—	2.4	—	1.1	2.7	—	16.7	0	0	8.4	4.0	8.5	10.7	tr.	0	5.7
Free NH_3 P.P.M.	0.5	0.9	0.6	2.0	0.8	2.5	1.3	0.6	1.9	0.4	1.3	0.7	0.4	0.5	0.4	0.6	0.04	1.7	0.66
Alb. NH_3 "	6.0	0.8	0.8	5.2	0.8	6.7	0.6	0.5	—	0.4	0.7	0.6	0.2	0.5	0.3	0.6	—	6.0	0.6
Total N "	8.8	3.0	2.1	8.4	2.8	10.6	2.7	2.3	—	8.8	1.6	1.8	3.8	1.1	3.8	9.8		9.0	3.8
Alkalinity as CaO	107	85	74	74	79	79	79	68	—	57	81	87	39	79	79	90	110	87	76
pH *	—	—	6.9	—	6.9	7.1	6.9	6.5	6.3	6.3	6.9	6.9	6.9	6.9	6.9	7.5	7.4	—	—
Chlorides, P.P.M.	14	14	14	28	14	14	14	14	—	18	14	21	11	28	32	—	25	18	16
Opalescence %	79	99	99	—	99	71	99	99	—	—	—	—	—	—	—	—	—	75	99
Suspended Solids P.P.M.	—	—	—	47	—	80	—	—	—	—	—	—	—	—	—	—	—	63	≠
Ash Susp. Solids "	—	—	—	10	—	17	—	—	—	—	—	—	—	—	—	—	—	14	≠
Total Solids, P.P.M.	—	—	—	—	—	—	—	—	—	—	254	284	—	268	242	230		—	255

Note: I = Influent, E = Final Effluent, Stability (Methylene Blue at 27° C.), All Samples Stable More Than 96 Hr. ≠ Suspended Solids in Effluent Too Small to Measure.

* pH Determination Undoubtedly Too Low Until July 12; Determination Made Colorimetrically; the Last Two Were Determined Electrometrically.

is very clear, has a B.O.D. of about 5 p.p.m. and contains an average of 5.7 p.p.m. nitrates.

It is of interest to compare the river water with the effluent from the plant. The stream bed is strewn with boulders and rocky ledges over which the water dashes, providing excellent reaeration. During a 100-kilometer trip by automobile along the stream numerous anglers were observed. The effluent of the plant compares favorably with the river water.

Power Consumption

The total power consumption for aeration, sludge stirring, etc. amounts to about 60 KWH per day. The different units required the following power:

Motor	490	Watts
Reduction Gear and Waterwheel	216	"
2 Agitators	85	"
6 Bearings	66	"
Aeration	1668	"
Total	2525	Watts = 2.5 KWH/hr.

This power consumption is comparatively high, on account of the low flow, but is the same for 92,500 gallons of waste, the capacity of the plant.

Summary

A surface aeration (brush) activated sludge plant is successfully treating dairy waste in Belgium. The plant is located at Hamoir. In September, 1933, it was treating about 37,000 gallons of waste per day. Analyses show that the effluent compares favorably with the water of a mountain stream into which it is discharged. Cost of construction was low. The plant is operated by a factory laborer, who makes routine tests, but analytical results given were obtained by the senior author. The plant is designed to handle the wastes from 25,000 liters of milk daily, or a waste production of about 92,500 gallons. The sludge from the primary settling tank is mixed with the waste activated sludge and digested. Supernatant liquor of the digester was very clear.

Acknowledgment

The authors are indebted to Director Perry of the Nestlé Works at Hamoir for opportunities afforded and are grateful for the courtesies extended.

Editorial

SEWAGE SPECIALISTS

Sewage is apparently undergoing a metamorphosis that may make it difficult for us to recognize the common or garden variety. We have long considered sewage to be the black sheep of the *aqua* tribe, the outcast and untouchable offspring of the *pura* family. The spent water supply has run to the sewers in disgrace, with a gray and ashy appearance often darkening into a black and villainous mien before the treatment plant was reached. No hand was raised to curb the living denizens of the liquid mess, and no prophylactic doses were administered to abort the inevitable malady—anaerobiosis. The sewage just kept running, like ole man River, and the bacteria lived and died in their own wild way, untrammelled by human intervention.

When the treatment plant was reached, effort was made to regiment the living organisms, to set this group at work on the digestion of the solids, that group on the oxidation of the liquid, and finally to wipe out the remaining bugs by a dose of chlorine. The diagnosticians prescribed the old-fashioned remedies of rest (detention), fresh air, and only small doses of drugs. The patient usually survived this treatment but recovery was a little slow.

A new school of sewage doctors began to find fault with this *laissez faire* type of treatment and urged that more strenuous measures be taken to restore sewage to a respectable, stable member of the *aqua* tribe, by addition of substances deficient in the ordinary diet of the organisms, or by improved and intensified ventilation and aeration. This school of homeopaths (represented by the PH degree) believed in small doses of lime for the solids, and their colleagues (DO degree) prescribed more oxygen for the liquid. If infection had to be checked, specialists with the CL degree were called in.

Some of the forward-looking investigators at this time hoped to restore old man sewage's health to a point where he could do a little profitable work to pay for his upkeep. For a time it seemed as though he could produce fertilizer profitably, but this hope soon waned. Other students put him to work making gas, and this activity seemed to agree with him as long as he worked in a warm, well-regulated environment, although he still was far from self-supporting. With no illusions concerning the income-producing possibilities of the old fellow, another group proposed to support him as economically as possible, with prompt incineration of all his wastes and offal.

About this time, specialists of a new or revived school appeared, whose slogan was speed and more medicine. Drugs and chemicals were again introduced, and complicated prescriptions were written, which recalled similar dosages familiar to sewage doctors of a past generation. However, the new school pointed to the short convalescence required, due to the rapid effect of the large doses prescribed. Iron tonics were used liberally; the patient's reaction was kept on the alkaline side; and anaesthetics were used when necessary. There still seemed to be one embarrassing difficulty. Whereas, in human relations, your best friend will not mention BO, among the sewage specialists it is fully discussed and constantly referred to as an index of the health of the patient, although the term used among sewage doctors is usually lengthened to BOD in a polite effort to avoid direct reference to this annoying yet universal malady. It seemed that the rapid treatment prescribed by the new specialists, with large doses of expensive medicine, did not rid the patient of all of his BOD, but a faint aura still clung to him. One corps of specialists, however, discovered that this residual BOD could be practically eliminated by exposure to light (type ZO).

While these doctors were working on their problems, a few municipal specialists brought up the possibility of combining two responsibilities, by placing sewage's disreputable cousin, garbage, in the same room as sewage, and treating both at reduced expense. This possibility apparently will depend upon the temperament of the two patients; garbage may have such an irritating and overbearing influence on his cousin as to complicate and increase the expense of treatment, either of each or both.

With these various schools of specialists now prescribing for the treatment of sewage, old man public, who pays the bills, may be pardoned for thinking, with Omar Khayyam: "Myself when young did eagerly frequent doctor and saint, and heard great argument about it and about: but evermore came out by the same door as in I went." The less skeptical laymen, however, will have faith that further research, experience and cost records will soon demonstrate the most economical and most efficient course of treatment for this ubiquitous municipal patient.

Proceedings of Local Associations

NEW YORK STATE SEWAGE WORKS ASSOCIATION

SIXTH ANNUAL MEETING

New York City, January 16, 1934

The Sixth Annual Meeting of the New York State Sewage Works Association was held at the Hotel McAlpin, New York City, on January 16, 1934. The attendance of 198 at the meeting was the largest ever recorded in the history of the association. At the business meeting Morris M. Cohn (Schenectady), Linn H. Enslow (New York) and Henry W. Taylor (New York) were elected to the Executive Committee in place of W. P. Gyatt, Carl L. Howell and Earle B. Phelps, whose terms of office expired. Edmund B. Besselievre of New York was elected president, and Morris M. Cohn of Schenectady, vice-president. A. S. Bedell, State Department of Health, Albany, was reappointed secretary-treasurer.

Following the business session Professor Earle B. Phelps presented a very interesting preliminary report on an "Investigation of Pollution of the Hudson River," which was briefly discussed by George A. Soper, George W. Fuller and Richard A. Gould. Dr. A. J. Fischer of The Dorr Company presented an excellent paper on "Digester Overflow Liquor—Its Character and Effect on Plant Operation," which was discussed by Weston Gavett and C. C. Agar. In the absence of C. E. Keefer, engineer in charge of sewage treatment, Baltimore, Md., Mr. Hedgepeth read Mr. Keefer's very timely paper on "The Results of Circulating Sludge *vs.* No Circulation in Separate Digestion Tanks," based on experiences at Baltimore. This paper was discussed by A. J. Fischer, W. Rudolfs and Henry W. Taylor.

President Anselmo F. Dappert presided at the luncheon and presented the Kenneth Allen Memorial Award for 1933 to Lawrence L. Luther of Freeport for the most meritorious paper of a technical and research nature presented during the year, and to Morris M. Cohn of Schenectady for the most meritorious report on the operation of sewage treatment works presented during the year. Harrison P. Eddy, president-elect of the A. S. C. E., was the principal speaker, using as his theme "Developments in Sewerage and Sewage Treatment During 1933." President Dappert then introduced Arthur S. Tuttle, State PWA Engineer, New York City, who gave an informal talk on the "Present

Aspects of Federal Aid to Sewerage'' and answered numerous questions presented by those present.

At the afternoon session Major G. H. Gleason, Director of Research with the Guggenheim Brothers, New York City, gave a paper on ''Results from Six Months of Operation of a Chemical Precipitation Demonstration Plant at Chicago,'' the discussion on which was opened by Wellington Donaldson and Alexander Potter, followed by a written discussion prepared by Langdon Pearse. This paper provoked considerable discussion and proved of great interest to all. Andrew N. Holmstrom of The Norton Company, Worcester, Mass., gave a well illustrated paper on ''The Selection and Utility of Porous Diffuser Plates and Holders,'' which was discussed by F. C. Roe of the Carborundum Company. Professor Thorndike Saville of New York University gave a brief paper on ''The 'Why' and 'How' of Sewage Research in New York State,'' referring particularly to the proposed work of the Committee on Sewage Research recently established by the Association.

In the evening, the members and guests of the Association joined the Sanitary Engineering Division of the American Society of Civil Engineers in the annual dinner of the latter. This pleasant custom, started two years ago, has become a permanent feature of the annual meeting. Professor Charles G. Hyde of Berkeley, California, presided as toastmaster and introduced the speaker of the evening, Abel Wolman, State PWA Engineer and Chief Engineer of the State Board of Health of Maryland. Mr. Wolman in his usual delightful way spoke of his experiences in connection with the PWA and CWA projects in Maryland.

A post-convention trip was made to the Rockville Center sewage treatment plant, where a recent full scale installation has been made for the vacuum filtration of sewage and sewage effluent with additional facilities for dewatering sludge and waste cake prior to incineration.

The next meeting of the association will be held in Jamestown, probably on June 15 and 16, 1934.

During the afternoon session on Tuesday, the association unanimously adopted the following resolution:

''Whereas, the successful operation of sewage treatment plants and their service to our communities depend upon efficient supervision, and

''Whereas, uninterrupted tenure of office of competent and experienced operators is highly necessary to accomplish this end,

''Now, therefore, be it resolved: that it is the sense of the N. Y. S. S. W. A. in annual meeting assembled that the Public Health Law be amended to more adequately secure these results through enlargement of the functions of the Public Health Council to include the fixing of qualifications of plant operators, or by any other means.

"Be it further resolved, that the New York State Commissioner of Health be requested to use any means at his command to secure these results."

A. S. BEDELL,
Secretary-Treasurer

SCHOOL HELD FOR SEWAGE WORKS OPERATORS IN WISCONSIN

The second annual school for sewage treatment plant operators was held in Madison, Wisconsin, during the period January 8–13, 1934, with twenty operators in attendance. This school has as its objective to acquaint the operators with the fundamentals of sewage treatment and to provide instruction in the methods for making control tests. The school was sponsored jointly by the Wisconsin League of Municipalities, State Laboratory of Hygiene, the Bureau of Sanitary Engineering of the State Board of Health, and the Hydraulic and Sanitary Engineering Department, University of Wisconsin. Those attending the course were, for the most part, operators of small municipal sewage treatment plants. The course outlined was accordingly presented in such manner as to provide maximum information of practical value in securing efficient operation of small plants. In addition to regular personnel of above mentioned state agencies the teaching staff included Mr. Walter Sperry, Aurora, Illinois; Mr. C. O. Bruden and Dr. B. Domogalla, Madison; and Mr. Oscar Ward, Marshfield. The school was conducted in the Hydraulic and Sanitary Engineering Laboratory at the University of Wisconsin and consisted essentially of lectures and discussions of various plant operating problems in the mornings, followed by illustrations in laboratory work in the afternoon sessions.

The subjects covered by the course were as follows:

1. General Theory of Sewage Treatment,
   By L. H. Kessler, Asst. Prof. Hyd. and San. Engr., U. of Wis.
2. The Necessity of Sewage Treatment,
   By L. F. Warrick, State Sanitary Engineer, Wis. State Board of Health.
3. Laboratory Service in Sewage Treatment,
   By Dr. M. Starr Nichols, Chief Chemist, State Lab. of Hygiene.
4. Source and Method of Disposing of Industrial Waste,
   By J. M. Holderby, Asst. San. Engr., Wis. State Board of Health.
5. Educating the Public to Sewage Treatment,
   By W. Sperry, Supt., Sewage Treatment Plant, Aurora, Ill.
6. Measurement of Sewage,
   By F. M. Dawson, Prof. of Hyd. and San. Engr., U. of Wis.

7. Sludge Digestion Problems,
   By E. J. Beatty, Asst. San. Engr., Wis. State Board of Health.
8. How a Sewage Plant Operator Looks at His Job,
   By O. Ward, Sewage Plant Operator, Marshfield.
9. New Methods of Sewage Treatment,
   By O. J. Muegge, Asst. San. Engr., Wis. State Board of Health.
10. Sewage Sludge as a Fertilizer,
    By Dr. B. Domogalla, City Bio-Chemist, Madison.
11. The Use of Chlorine in Sewage Treatment,
    By C. O. Bruden.
12. Sewage Gas, Its Collection and Use,
    By O. J. Muegge, Asst. San. Engr., Wis. State Board of Health.
13. The Stream as a Measure of Sewage Plant Efficiency,
    By H. Ruf, Instr. Hyd. and San. Eng., Univ. of Wisconsin.
14. Daily Care of a Sewage Plant,
    By E. J. Beatty, Asst. San. Engr., Wis. State Board of Health.

The laboratory work was performed under the direction of Harold Ruf, J. M. Holderby, and E. J. Beatty. Certificates of accomplishment were issued to the operators at a dinner held at the conclusion of the course. Speakers at the dinner session included Prof. F. E. Turneaure, Dean of the College of Engineering, Dr. C. A. Harper, State Health Officer, A. L. Kurtz, Asst. Federal-State Engineer for the P.W.A., F. N. MacMillin, Executive Secretary of the Wisconsin League of Municipalities, W. G. Kirchoffer, Consulting Engineer, Prof. F. M. Dawson, and L. F. Warrick, State Sanitary Engineer. The school concluded with an inspection trip to local sewage treatment plants conducted by John Mackin, Superintendent of Sewage Treatment for the Madison Metropolitan Sewerage Commission. It is anticipated that the school will be continued on an annual basis to assist in improving the status of sewage treatment plant operation in Wisconsin.

Sewage Division, Texas Section, S. W. W. A.

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THE NEW ENGLAND SEWAGE WORKS ASSOCIATION

NOTICE OF MEETING

The next meeting of the New England Sewage Works Association is to be held at the Pickwick Arms Hotel, Greenwich, Connecticut, April 30, 1934.

Book Review

Sewage Disposal in Germany. By Dr.-Ing. E. h. J. Brix, Dr.-Ing. E. h. Karl Imhoff and Prof. Dr. R. Weldert. Published by Gustav Fischer, Jena. 1934. In Two Volumes. Price, Paper Covers 138 Marks, Bound 144 Marks.

Superlative adjectives are needed to do justice to this monumental work. The first volume contains 972 pages and 298 illustrations, the second 600 pages and 406 illustrations. These weighty tomes (about eight pounds) contain information of great value, collected by laborious effort on the part of the distinguished authors. The data are authoritative and quite up-to-date. It is unfortunate that the price is so high (about $57 at the present exchange) that few Americans can afford to own a set of the books. The excessive cost will probably limit the circulation in the United States.

The first volume contains detailed description of sewerage systems and sewage treatment works of approximately 1600 cities and towns in Germany. Towns of less than 10,000 receive usually approximately 500 words, while Berlin rates 42 pages, Frankfurt-on-Main 21, Cologne 19, Leipzig 17, Munich 16 and Dusseldorf 16.

The descriptions for the larger cities are usually complete enough to give a comprehensive picture of the sewerage system and treatment works, although results of operation are not given, neither is there any detailed description of sludge disposal. Costs of operation of the treatment works are frequently presented. Plans of treatment works occasionally accompany the text. Experimental work is described and future extensions outlined.

The second volume is a comprehensive review of the general principles of sewer design and sewage treatment plant operation. The latter is divided into chapters dealing with screens, settling tanks, chemical treatment including chlorination, biological filters, activated sludge, land disposal, stream pollution, sewage and sludge examination, sanitary districts, water consumption and tabulation of types and sizes of sewage treatment works in Germany. This second volume is quite readable and not of the encyclopedic type of the first volume.

The names of authors of the second volume familiar to American readers are Imhoff, Weldert, Sierp, Fries, Mahr and Helbing (deceased). Dr. Sierp has an excellent chapter of 58 pages on the activated sludge process. This chapter, as well as others, is a thorough exposition of the development of the process in Germany, but the references to American

and English plants are sometimes inaccurate and often confused. For example on two pages (319 and 320) the Tenafly plant is referred to as the "Texas, New Jersey" plant; Withington is spelled "Pittington"; the selling price of activated sludge per ton at Milwaukee and Pasadena is given as 25 and 30 pounds sterling instead of dollars (and even in dollars now much lower). The air consumption at the Chicago North Side activated sludge plant is reported as 9 air to 1 sewage (1.2 cu. ft. per gallon) whereas it is actually only one-third this amount. It is unfortunate that the sections dealing with American and English work were not referred to American or English engineers to be checked. Notwithstanding these minor inaccuracies the chapter on activated sludge is quite stimulating and interesting.

A short chapter on chemical precipitation describes the various processes that have waxed and waned in Germany, comprising the use of various precipitants. A bibliography of 63 references is of especial value.

Dr. Imhoff in two pages reviews the present status of sewage treatment and predicts further development of separate digestion, location of treatment plants within city areas, but with sludge-drying beds at a distance, use of sewage farms (as at Berlin) for small and average sized cities, and activated sludge for large cities. Trickling filters appear to be waning in popularity.

Dr. Weldert contributes an interesting chapter on stream pollution.

The final section of Volume II is a tabulation of the water consumption in 948 German cities.

Other features include a chapter on costs of construction and operation of German sewage treatment works; an inadequate chapter on industrial wastes; full descriptions of the Ruhr, Emscher and other sewage disposal districts; a complete and valuable dissertation on sedimentation and sludge disposal by Dr. Fries; and a long and very general chapter on streams and utilization of water.

The contents of Volume II are of universal interest, as contrasted with the more specifically German interest in the contents of Volume I. It would be a valuable contribution to the international literature on sewage treatment if Volume II could be published separately and in a cheaper edition. In the reviewer's opinion, this would lead to a far greater distribution of this excellent and valuable treatise.

F. W. MOHLMAN.

Reviews and Abstracts

H. W. STREETER

ADDITIONAL SETTLING TANKS FOR THE TAFELWERDER PLANT IN HALLE

By Dr.-Ing. Heilmann and Dr.-Ing. Muller

Gesundh. Ing. 56, 571 (1933)

Because of the extreme pollution of the Saale River the Halle treatment plant was enlarged during 1932 and 1933. The original plant consists of 24 Imhoff tanks, each about 26 feet in diameter. Three tanks are connected in a group with a common settling tank which has a capacity of 47,300 cubic feet, a length of about 78 feet, width of about 16.5 feet and an average depth of 4.6 feet. The sludge slots in each settling tank have a total length of about 1260 feet (one foot for each 37.5 cubic feet of settling tank capacity). This proportion is very large and the sewage, as it passes through the tank, is contaminated by sludge liquor. The gas chamber under the collector is very small, only 8470 cubic feet. The sludge digestion rooms of the Imhoff tanks have a total capacity of 191,300 cubic feet measured below the slots. Since this has not been sufficient for some years, two additional secondary digestion tanks, equipped for heating and with a total capacity of 83,000 cubic feet, were erected in 1929 and 1931.

The settling tanks were enlarged because of an increase in the amount of sewage. The average amount of sewage from an included population of 190,000 in 1930 was 11 cubic feet per second and the largest hourly flow was 15.5 cubic feet per second. This is equivalent to 37.5 gallons per capita per day.

The new settling tanks were designed to serve a population of 240,000 and to provide a detention period of 1.5 hours for a sewage flow of 39 gallons per capita per day. The settling capacity necessary was estimated at 114,300 cubic feet. The old settling tanks had a capacity of 47,300 cubic feet and the new ones must provide 67,000 cubic feet. As the digestion capacity of the old plant together with the new secondary digestion tanks seemed adequate, there was no occasion to provide more digestion space. New separate digestion tanks may be added later. Imhoff tanks with small digestion capacity were chosen because of simplicity of operation.

Each of the four new settling tanks has a gas collection apparatus, two settling chambers and a sludge room. The settling chambers, which

are connected to the sludge tanks by slots, are about 82 feet long, 13 feet wide and on an average 7.5 feet deep. The total length of the sludge slot is 656 feet which amounts to 102 cubic feet of digestion room capacity per foot of slot as compared with 37.5 cubic feet in the old plant. This new proportion of slot to tank capacity is satisfactory.

The sludge digestion capacity is only 28,240 cubic feet and with a daily sludge collection of 3500 to 5250 cubic feet only a few days' sludge can be accumulated. The sludge digestion room is divided longitudinally into three hoppers of different size, the one at the influent end of the settling tank being larger because most of the sludge is collected there.

The direction of flow through the settling tanks is not reversible. The effluent weirs are adjustable so that the load on any tank can be regulated at any time. Scum is collected with the aid of floating baffles and forced by hand over a fixed weir into a sludge channel. The sludge from the new plant passes through an underground pipe to the pump sump of the old Imhoff tanks and is pumped from there to the separate digestion tanks.

Construction of the new plant was begun in June, 1932, and completed in May, 1933, at a cost of about $46,250. The project was carried on as emergency work on a 40-hour-a-week basis and using as many workers as possible.

In starting the new plant, ripe sludge was first placed in the digestion tanks, the tanks were filled and allowed to stand quiet for several days and then placed in full operation. The amount of settleable solids removed increased from 89 to 99 per cent. In the effluent the settleable solids do not exceed 0.2 c.c. per liter. Sludge is withdrawn from the digestion tank every two or three days.

G. P. EDWARDS

THE COMPOSITION OF LEIPZIG SEWAGE

BY DR. K. VIEHL

Gesundh. Ing. **56**, 283 (1933)

A population of 650,000 is contributory to the main sewage treatment plant of Leipzig. Because of the economic depression there now is an average dry weather sewage flow of only 26,400,000 gallons per day or about 40 gallons per capita per day. The sewage from the sewerage system, a combined one, tends to be septic because of the numerous domestic privies which still exist. Of the 29,000 buildings in the city only 5,000 discharge directly into the sewers, 8,500 have overflow pits from which a partially digested liquor is discharged to the sewer

and the remainder have dry closets from which the solids must be withdrawn. Only about one-sixth of the feces goes to the treatment plant. Industrial wastes, which average about 20 per cent, are received from such industries as slaughter houses, wool combing, yeast, gas, fur dressing and dye plants. The water from some of these is partially purified before being discharged into the sewer.

In 1931 the drinking water consumption amounted to 28 gallons per capita per day. The difference between that amount and the 40 gallons per capita per day is explained by ground water seepage, water from two brooks and by the fact that some factories have their own wells.

The investigation was carried on for a year beginning in the fall of 1931. Samples were collected only during dry weather every two hours out of the twenty-four, after the sewage had passed the Dorr grit chambers and the coarse screen (bars about 0.6 inch apart) and were analysed as quickly as possible after collection. In case the samples had to stand more than eight hours before analysis they were preserved with 7 c.c. per liter of 20 per cent neutralized phenol solution. This preservative was more satisfactory than chloroform or sulphuric acid. The sewage was passed through filter paper before making the determinations of permanganate consumed, chlorine number, dissolved solids and nitrogen. The B.O.D. was determined on the settled sewage and phosphoric acid, fat and iron were determined on a well-shaken raw sewage.

The most concentrated sewage was obtained at the time of heaviest flow. During dry weather about ten times as much organic matter was received at 12 o'clock, noon, as at 6 a.m., the weakest sewage being received between 6 and 8 a.m. The ammonia nitrogen and the chlorine number reach a maximum about noon, whereas the permanganate consumed, organic nitrogen, chlorides and B.O.D. remain fairly constant until evening. The settled solids were highest at 4 p.m. From an average of 380 samples the permanganate consumed was about 20 per cent lower in summer than in winter while the consumption was about 13.5 per cent higher in the summer. The sewage contained 48 p.p.m. potassium (57.8 p.p.m. K_2O), 17.5 p.p.m. P_2O_5, 62 p.p.m. of total nitrogen and 1.25 p.p.m. H_2S most of which was combined with iron. It has been suggested that the H_2S causes bulking of activated sludge by killing the protozoa and permitting the *sphaerotilus* to predominate. This does not seem to be true in Leipzig because the activated sludge of the experimental plant always contains a good many protozoa of all kinds even during bulking. The protozoa tolerate 4 p.p.m. H_2S without noticeable harm if the sewage sludge mixture is aerated.

The sewage contains on an average 203 p.p.m. settleable solids, 129 of which are organic. These values are somewhat too low because heavy

sludge particles settle in the bottom of the sewer and consequently the following calculations should be based on 220 p.p.m. of solids and 140 p.p.m. organic matter. From these values 48,400 pounds of dry solids with 30,800 pounds of organic matter should be collected each day. These figures agree reasonably well with the values obtained during operation. This amounts to 33 grams per capita per day of fresh solids of which 21 grams are organic matter. Although this value includes some industrial waste it is considerably lower than Imhoff's value of 30 to 44 grams per day because of the smaller amount of feces.

It was estimated that 277,400 gallons of 98 per cent excess sludge per day would be collected from an activated sludge plant. This sludge would contain 46,000 pounds of dry solids of which 33,000 pounds would be organic matter or 32 and 23 grams per capita per day, respectively. These values would be increased about one seventh if all the feces were included.

A number of laboratory experiments were carried on at 122° to 131° F. to determine the amount of gas to be expected from a full scale digestion plant. In eight series of experiments carried to the practical limits of digestion, 526 c.c. of gas were obtained from 1 gram of organic matter contained in the raw sludge. With activated sludge the yields were about 33 per cent lower. For every gram of organic matter digested, 1.2 grams of gas were obtained from 1 gram of raw sludge and 0.8 gram of gas from 1 gram of activated sludge. In practice the gas yield is usually somewhat lower because of unavoidable small losses and because the sludge is not always as well digested. The average, 30,800 pounds per day of organic matter in the raw sludge, would yield 226,000 cubic feet of gas per day or 0.36 cubic foot per capita per day. Including all the feces the 46,200 pounds of organic matter would give 339,000 cubic feet of gas per day, corresponding to 0.53 cubic foot per capita per day. The activated sludge, with its 37,400 pounds of organic matter including all feces, would yield 190,000 cubic feet of gas so that a total of 529,000 cubic feet or 0.82 cubic foot per capita per day would be obtained. The gas obtained from storm water sludge, which is not included, might raise this value considerably.

G. P. EDWARDS

THE DETERMINATION OF MOISTURE IN SETTLED SLUDGE

BY DR. H. BACH

Gesundh. Ing. 56, 417 (1933)

In most laboratories engaged in sewage investigations, moisture in settled sludge is determined by difference. A definite amount of wet

sludge is weighed and the moisture evaporated on a water bath. After it has been dried to constant weight in an oven, the sludge is weighed and the moisture of the sample obtained by subtraction from the original weight. Loss of the easily oxidizable sludge, which may smolder at 105° C., is prevented by drying in a water-jacketed oven. During evaporation the water in the inside of the cake can be driven off only by pulverizing the sludge, a procedure which usually results in loss of material.

Errors in the moisture determination are particularly noticeable in the discrepancies between the gas yields from digestion of sludge and the amount of organic matter digested. The weight of the gases obtained is often considerably higher than the weight of the organic matter digested, as calculated from the loss on ignition of the dry substance, again a determination by difference.

The apparatus suggested first by Hofmann and Marcusson and later by Schlepfer, for the determination of moisture in liquid and solid fuels, seems to be suitable for the direct determination of moisture in sludge. In this method the last traces of water are removed from the sludge by distillation with xylol vapor. The cooled distillate is collected in a measuring tube in such a way that the water separates out underneath and can be sharply separated from the xylol. The organic matter of the sludge, volatile with the water or xylol vapor, does not affect the results since it remains soluble in the xylol. Enough sludge is weighed into a 100 c.c. flask so that the amount of water to be collected will not exceed 12 c.c., 50 c.c. of xylol saturated with water are added and the flask is attached to the apparatus with a good cork stopper. The flask is heated in a sand bath and the xylol, boiling at 135° C., carries the water vapor with it. The mixed vapor condenses in the measuring tube and the excess xylol flows back into the sample flask so that it may redistill and carry new water vapor. When the meniscus in the measuring tube no longer rises all the water has been driven off from the sludge. By careful operation 99 to 99½ per cent of the water present in the sludge is distilled over into the measuring flask. New apparatus should be checked by collecting the water distilled from an artificial sludge, that is, a dried sludge to which a definite amount of water is added.

To determine the volatile matter, another weighed sample is dried in a platinum or quartz dish on a water bath and then ashed without weighing the dried material. The volatile matter is found by subtracting the weight of the water and the weight of the ash from the weight of the sludge.

G. P. EDWARDS

THE PURIFICATION OF WASTES FROM STARCH FACTORIES

By Dr.-Ing. W. Husmann, Zurich

Gesundh. Ing. 56, 332 (1933)

The sewage from a wheat starch plant is distributed by trickling channels on to an experimental sprinkling filter which contains 530 cubic feet of filtering material and is 10 feet high. Since the distribution is very poor, it can be assumed that only about two thirds of the filter, about 350 cubic feet, was used for biological action.

In the first series of experiments 1,057 gallons of sewage were fed to the filter daily. A secondary settling tank removed the sludge discharged from the filter. The permanganate demand was reduced 85 per cent (from 3,076 to 452 p.p.m.) in the sprinkling filter and the pH was increased from 3.3 to 6.1. Although the soluble organic matter was decreased from 1,455 to 610 p.p.m. the reduction was not enough to maintain a stable effluent for more than three days. When the load on the sprinkling filter was reduced to about 800 gallons per day the effluent was stable and the pH increased to 8.0.

The amount of waste in the starch factory is 47,500 gallons each working day. If the total amount of waste were treated, a sprinkling filter of about 32,000 cubic feet capacity, costing approximately $10,000, and a secondary settling tank, costing about $250, would be necessary. This total cost of $10,250 could not be borne by most factories.

To obtain a satisfactory effluent the waste could be treated more intensively in one filter or in stages. More intensive action can be obtained by covering the sprinkling filter with a solid material impermeable to air and by drawing sufficient air through it. By this arrangement about 3.74 gallons of waste could be treated per cubic foot of filtering material so that for 47,500 gallons per day a sprinkling filter of 12,700 cubic foot capacity would be needed. A supply of 700,000 cubic feet of air per day or 111 cubic feet of air per cubic foot of waste should be sufficient to produce a satisfactory effluent in all cases. The cost of such a sprinkling filter would be about $3,750.

In stage purification the starch wastes would be treated electrolytically in the first stage and on a sprinkling filter as a second stage. In the electrolytic treatment the soluble organic matter is decreased about 67 per cent (from 1,455 to 480 p.p.m.). Although the effluent contains a rather large amount of iron (298 p.p.m.) this is not a disadvantage because it flocs out with aeration and helps to remove part of the colloidal matter. The colloidal sludge resulting from the electrolytic treatment must be removed in the secondary settling tank before distribution on the

sprinkling filter. An aerated sprinkling filter can handle about 15 gallons of this electrolytic effluent per cubic foot of filtering material. In order to treat 47,500 gallons of waste, a sprinkling filter 3,177 cubic feet in capacity and costing about $900 would be needed.

It is estimated that the first cost for treatment of the 47,500 gallons of waste would be about $4,000 for the intensive treatment and about $1,850 for the stage treatment. The annual operating cost for the intensive treatment would be about $500 and for the stage process about $625.

Both of these methods are useful in the treatment of other wastes with a high organic content such as those from distilleries, wine presses, and sugar factories.

G. P. EDWARDS

FIVE YEARS' OPERATION OF THE MILWAUKEE ACTIVATED SLUDGE PLANT

ANON.

Public Works, **46**, 10–11 (Nov., 1933)

This article is based upon a paper by Darwin W. Townsend, formerly Principal Assistant Engineer, now Consulting Engineer, Milwaukee Sewerage Commission. It covers the period from January 1, 1928, to January 1, 1933.

The activated sludge plant consists of 24 reverse-flow, ridge-and-furrow aeration tanks and 15 sedimentation tanks with Dorr and Tow-Bro sludge removal mechanism. Before entering the plant, the sewage is screened and passed through a grit chamber. Oliver 12×14 ft. continuous vacuum filters partly dewater the excess sludge, which is dried in modified Atlas type direct-indirect rotary dryers. The processed sludge is sold for fertilizer under the name Milorganite. The screenings and grit are incinerated.

With the exception of three temporary suspensions totaling five days, the plant was in continuous operation during the five year period. The average sewage flow was 80.48 m.g.d. The sewage was very uniform in character and strength. The average B.O.D. of the sewage was 270 p.p.m. The nitrogen content averaged 40.6 p.p.m. The monthly temperatures varied from 49° F. to 71° F. The pH of the sewage averaged 7.16 in 1928–1930, and 7.4 in 1931–1932.

Aeration.—The average period of aeration was 5.34 hours in the tanks and 1.26 hours in the various supply channels. The tanks received 1.22 cu. ft. of air per gallon and the channels 0.28 cu. ft. Enough sludge was returned to the tanks to maintain a mixed liquor suspended

solids content of approximately 3,000 p.p.m. The effluent showed a reduction of 97.5 per cent of the initial bacteria, 93.5 per cent of suspended matters and 95.4 per cent of B.O.D. Of the 24 tanks, an average of 22.5 tanks were in continuous service.

Sedimentation.—The average detention period of the sludge in the sedimentation tanks was 2.3 hours. The suspended solids content of the sludge averaged 1.06 per cent in the years 1928–1930; 1.23 per cent in 1931; and 1.37 per cent in 1932. Plant extensions are being designed on the basis of 1.5 per cent suspended solids with 2.0 hours detention. The tanks functioned at an average rate of 1,080 gallons per square foot per 24 hours of mixed liquor, or 812 gallons of raw sewage. The effluents contained 0.8 p.p.m. of nitrite, 2.28 p.p.m. of nitrate and 18.4 p.p.m. of suspended solids.

Sludge Disposal.—During the five year period, 162,800 tons of fertilizer were produced. The optimum pH for maximum filtration rates was determined each day prior to filtration. The optimum pH values averaged 3.87. Both sulphuric acid and ferric chloride were used until the end of 1931; since that time only ferric chloride has been used. The average dosage of ferric chloride is about 144 pounds per million gallons of sewage. The moisture content of the sludge was reduced from 98.63 per cent to 83.6 per cent by the vacuum filters and further reduced to 3.83 per cent by the driers. Each square foot of filter averaged 158.5 pounds of dewatered sludge cake per 24 hours and each dryer produced an average of 17.5 tons of fertilizer per day.

Incineration of Screenings and Grit.—The moisture content of the coarse screenings is reduced from 88 to 72 per cent, and the fine screenings to 77 per cent in Tolhurst horizontal centrifugal machines. The material is then burned in 20-ton oil-fired Morse-Boulger refractory arch type incinerator units.

General.—Accelerated rates of sludge settling and solids concentration have occurred at times, notably during the summer of 1932. Microscopic examination of the activated sludge floc revealed the presence of abnormally large numbers of filamentous growths among the other and usual microorganisms present. The same conditions were noted in June, 1933. During the year 1930 the sewage flow was somewhat less in quantity but the sewage was stronger and the pH lower. This sewage was generally more resistant to treatment than the other sewages, though the removal percentages of suspended solids, bacteria and B.O.D. were somewhat higher than during the other four years.

Operation and Maintenance Costs.—The revenue from Milorganite decreased from $19.92 per million gallons of sewage in 1929 to $10.17 in 1932. The profit in 1929 was $1.68 a ton; in 1930, the loss was $2.72 a ton; in 1931, the loss was $5.92 a ton; and in 1932, the loss was $6.90 a

ton. The average annual cost, less the Milorganite revenue, of operating and maintaining the treatment plant, intercepting sewer systems, sewage pumping station, etc., but not including capital charges on the investment, was $14.78 per million gallons of sewage in 1929, $15.62 in 1930, $20.14 in 1931 and $22.93 in 1932. The cost of compressing one million cu. ft. of free air to 9 lbs. per sq. in. was $3.59. This makes the cost of air about $5.40 per million gallons of sewage treated.

P. D. McNamee

OSAKA, JAPAN'S GREAT INDUSTRIAL CENTER, INCLUDES MODERN SEWAGE DISPOSAL IN VAST DEVELOPMENT PROGRAM

By I. W. Mendelsohn

Public Works, **64**, 18–19 (Nov., 1933)

Osaka, situated in the southwestern part of the main island, has a population of 2,453,569. In 1925 an activated sludge experimental plant, consisting of a grit chamber, preliminary settling tank, ridge-and-furrow type of aeration tank, two sludge settling tanks and one re-aeration tank, was completed. The plant is situated in the west central part of Osaka and treats a dry weather flow of 1,280,000 gallons. Tests on this plant were made for the period 1925–1928. As a result of the findings, the City Planning Board of Osaka decided on a plan of sewage treatment which was approved by the Imperial Government on May 29, 1928. According to this plan, the city is divided into five separate sanitary districts, each with its own pumping stations and sewage treatment plant. It is expected that by 1935 the two central area plants will be in operation. The remaining plants will be installed as funds become available.

One of the central area plants is located on the Kizu River in the south central part of Osaka. It will have a capacity of 37.2 m.g.d. and will have an area of 14.5 acres. The plant will consist of two grit chambers, two preliminary settling tanks $90' \times 90' \times 13'$, six double around-the-end type spiral flow aeration tanks, three secondary settling tanks $110' \times 100' \times 13'$, and two sludge tanks 64′ in diameter by 12.5′. The grit chambers will have bar screens and mechanical scrapers. The air will be supplied to the aeration tanks through porous plates at a pressure of 7.1 pounds per square inch. The detention period in the aeration tanks will be 5½ hours and sludge of 98 per cent moisture equal in volume to 20 per cent of the sewage flow will be returned. The effluent will pass to the Kizu River.

The other activated sludge plant under construction for the central area of Osaka is located in the northwestern part of the city on the

Shinyodo River. It will serve a population of 451,000 in an area of 3.9 square miles. The plant will consist of two grit chambers, four pumps for dry weather flow and five for wet weather flow, two preliminary settling tanks 70′ × 70′ × 12′, six aeration tanks 608′ × 16.4′ × 15′, four secondary settling tanks 73.3′ × 73.3′ × 12′, and two sludge storage tanks 49.2′ in diameter by 12.5′. The daily production of sludge of 96 per cent moisture content is estimated at 116,500 gallons. The sludge will be barged to low areas, used for fertilizer or dumped at sea.

P. D. McNamee

CLEANING ACTIVATED SLUDGE AIR DIFFUSERS

(From article by W. L. Howe)

Public Works, **64**, 12, 24 (Dec., 1933)

The life of porous diffuser plates and tubes used in aerating sewage would be almost limitless except for clogging, which necessitates cleaning or discarding them at intervals.

Porous plates are clogged from both sides; on the under side with soot, oil and pipe scale and on the top with ferric hydroxide, lime and organic matter. Tubes may be found clogged by grease, soap, fibrous waste and organic matter. The deposit always penetrates into the plate, frequently ⅛ inch or more, depending on the porosity.

Scrubbing the surface with dilute hydrochloric acid only partially restores permeability. One city tried using a blow torch, which caused flaking off of the quartz surface layer of the plate. Plates made of aluminum grains do not flake in this way, though either kind may be cracked by non-uniform heating. Sand blasting with alundum grains has been partly successful if the plates were dried first.

It seems probable that permeability can be completely restored if the plates or tubes can be removed. The treatment recommended is: (1) soak in 33 per cent HCl for 3 to 4 hours; (2) wash; (3) fire to about 1000° C. The firing requires a furnace such that no flame impinges on plate or tube. Firing is continued for 12 to 16 hours. On three typical lots of plates treated in this manner, the following results were obtained:

Plate	Permeability Values (cu. ft.)		
	A	*B*	*C*
As received	1.5	5.5	2.5
Hcl. (33% sol. n.)	7.5	10.5	—
Firing at 1000° C.	13.5	14.4	8.5

The final permeability values were within 2 cu. ft. of the original before use.

It is reported that at one treatment plant nitric acid is being used and at another, 15 per cent solutions of caustic soda, in which tubes are boiled, restoring them to about 70 per cent of their original permeability.

Porous tubes can be readily removed and replaced, but plates are usually grouted and are difficult to remove. Designs of plate holders have been considered recently permitting ready removal of the plate for cleaning.

H. W. STREETER

CHLORINE FOR SMALL SEWERS

BY B. G. S. ROBINS

Public Works, 65, 38–39 (Jan., 1934)

The paper describes a test of chlorinating a small sewer at Webster Groves, Mo., for minimizing obnoxious odors.

Laboratory tests indicated that chlorine in a 12 per cent sodium hypochlorite solution, added at the rate of 35 p.p.m., eliminated the odor. The solution was added from 5 gallon glass carboys fitted with two-hole rubber stoppers. Through one hole was inserted a ⅜ inch glass tube extending to within 1/16 inch of the bottom. This acted as an air vent. Through the other a short glass tube was inserted, extending 3 inches above the stopper, and connected by ¼ inch rubber tubing to the desired point of application. The carboy was then inverted and rested on a wooden crate at a 60° angle. A pinch cock applied to the rubber tubing regulated the flow (2 drops per second gave a flow of ½ gallon per hour).

With the apparatus described, hypochlorite solutions were added at the outlet of small sewers, with a chlorine dosage of about 9 p.p.m. which was found by trial to be effective. By draining a small stream bed and eliminating pools, the required dosage was cut to 5 p.p.m.

Where the flow of sewage is sufficient to permit addition of the dry powder, the addition of hypochlorite can be facilitated by using a dry-feed machine. For larger volumes, use of compressed chlorine, with regulating equipment, would be the most economical.

H. W. STREETER

PLANNING AND FINANCING SEWAGE TREATMENT IN BIRMINGHAM (ALABAMA)

ANON.

Public Works, 65, 2, 15–17 (February, 1934)

Although the recently completed Ensley sewage treatment plant at Birmingham, Ala., has aroused much interest because of its low per capita cost (about $1.35) and correspondingly low operating cost, it is but one unit in a larger plan which includes construction, operation and financing of six related projects designed to give adequate treatment of the sewage of Birmingham and its suburbs, now exceeding 36 m.g.d. The population of this district is now 362,000 and these projects are designed for a population of 500,000 in 1947, at a total cost of $600,000.

Of particular interest is the Shades Valley plant, designed for chemical treatment to provide extreme flexibility in the degree of purification. This plant consists of a sewage meter, flash mixer, slow mixer or flocculator, 2 settling tanks, 2 digesters, 5 sludge drying beds and a main building housing the screen, chlorine and chemical dosing apparatus, pumps, laboratory and other facilities. It provides for six different combinations of treatment, ranging from plain sedimentation with or without chlorination to settling, coagulation with chlorinated copperas and free chlorine, flocculation and final sedimentation. Admixture of chemical sludge is also provided in the primary settling tank. An anthracite filter is planned to operate at 4 gals. per square foot per minute to remove the fine floc not removed by the secondary clarifier. Sludge from the plant will be digested in two stages, first in a heated tank and then in an unheated tank with floating cover. The construction cost of this plant, designed to treat 2 m.g.d. of sewage, is $85,000.

H. W. STREETER

ASSESSING DAMAGES FOR SEWAGE POLLUTION OF RIVERS

ANON.

Public Works 65, 2, 40 (February, 1934)

A law embodying a novel idea went into effect in Massachusetts last October, as affecting sewage pollution of rivers by cities.

To protect oyster consumers, the state department of health is required to examine the tidal waters and flats from which shell fish are taken. If it finds the pollution makes these areas unsafe, it is unlawful

to take shell fish from such areas unless they are purified by an approved plant before being used. If the shell fish industry warrants it, the department may approve construction and operation of a purification plant by the community in which the shell fish area is located and assess the cost against the several communities responsible for the pollution in proportion to their relative shares in causing the pollution. Presumably a city satisfactorily operating an adequate sewage treatment plant would not have to make such payments.

If this principle holds for the benefit of the shell fish industry, it would seem logical to apply it to the benefit of cities taking their water supplies from polluted streams, requiring all polluters of a stream above a given city to reimburse such a city for the cost of building and operating its water purification plant. This would seem to meet the objections raised by many cities, as for example at Waterloo, Ind., whose *Press* said recently: "So long as Fort Wayne is not going to build a sewage disposal plant to take care of the waste of that city, there is not much reason why Waterloo should do so for the sake of Fort Wayne's water plant."

H. W. STREETER

INCINERATOR AND SEWAGE WORKS COMBINED FOR CANAJOHARIE

By H. W. TAYLOR

Public Works 65, 2, 9 (February, 1934)

Canajoharie, N. Y., applied in September, 1933, for a P.W.A. loan and grant to construct a wastes disposal plant, consisting of an incinerator for garbage and refuse and a sewage treatment works including primary treatment only. By combining the construction and operation of the two plants several economies were possible, such as the use of one site and a single operating force, an opportunity for exchange of heat values and the convenience of incinerating the dry sludge if desired.

The main building of the plant was designed with the incinerator process at one end and the sludge digestion process at the other end, with screening, pumping and other sewage treatment equipment in the center. The settling tanks are in the rear of the building and the sludge drying beds parallel to the tanks. The first floor of the building contains the incinerator and stoking room, a hallway, the sludge digestion tank and motor room for the sewage pumps. The second floor contains the loading room for the incinerator, central hallway, office and the upper part of the digestion tank.

Pipe coils are to be installed in the last combustion chamber of the incinerator and connected to a hot water tank with capacity sufficient to supply the sludge tank with hot water for its heating coils for 24 hours daily, though the incinerator is used for only 8 hours. The storage tank will be controlled by thermostatic valves so that while the temperature in the hot water tank may rise as high as 200 degrees, the circulating water delivered to the sludge tank will be maintained at 125 degrees. In series with this hot water heating system will be installed a hot water heater using coal and a gas-fired heater. On Sundays the gas from the sludge tank will be diverted from the incinerator to this hot water heater.

The sewage treatment works consist of settling tanks with two hours retention of average flows, and separate sludge digestion. The digestion tank will be built of steel. It will be equipped with floating cover and other accessories. The settling tanks and sludge tank being located within the building, the operator can divide his time between these and the stoking room without leaving the building. Effluent piping for the settling tanks will be located at three points—about five feet from the outlet end, at the center point and at the quarter point near the inlet end. With proper proportioning of the effluent as drawn from these three different locations, it is expected that a better effluent will be obtained and a higher rate of flow maintained.

Three gas burners will be installed in three combustion chambers of the incinerator and gas from the sludge tank will be utilized to maintain temperatures in these chambers and to assist in complete combustion of the flue gases. The entire combined plant will be operated with a single attendant.

H. W. STREETER

THE INSTITUTE OF SEWAGE PURIFICATION

Proceedings, 1932.

269 pp.

These *Proceedings* were formerly known as "The Proceedings of Managers of Sewage Disposal Works." The incorporation of this group took place in November, 1932, at which time the name was changed.

As a great many of the papers published in these *Proceedings* are reprinted in *The Surveyor* from time to time, they have been abstracted from the latter publication. The present abstract will list the titles in the order in which they appear in the *Proceedings*, abstracting only those which have heretofore not been published.

Treatment of Ammoniacal Liquor from Gasworks. By J. Slater. Abstracted in THIS JOURNAL, **4**: 379 (1932).

Sludge Digestion as Applied at the Chorley Sewage Works. By J. Slater. *Ibid.*, **4**: 377 (1932).

Gasworks Liquor: Its Composition and Treatment. By A. Key. *Ibid.*, **4**: 570 (1932).

Combined vs. Separate Systems of Sewerage. By A. R. Ward. An ideal sewerage system provides for self-cleansing of the sewers at all times, so that the sewage reaches the outfall works in a fresh condition. With the combined system this ideal is never obtained since the sewers must be much larger than necessary for dry-weather flow and therefore they are flushed only at times of storms.

Amount of storm water reaching the sewers depends on amount and intensity of rainfall, on size of draining area, and on the degree of impermeability of the surface.

The Ministry of Health requirements for combined sewers are that such sewers must be capable of passing 6 times the dry weather flow, half of which shall be able to pass in six hours.

Analyses of samples taken over a considerable period from the storm tanks at Stockport showed that they were of a polluting character.

An argument in favor of separate systems is the reduction of pumping charges.

The Ruhrverband. By Reginal C. Shaw. Abstracted in THIS JOURNAL, **4**: 572 (1932).

On the Conversion of a Contact Bed to Rotary Sprinkler Filter. By E. B. Birkett. To determine the type of sprinkler to use when converting a contact bed into a sprinkling filter, careful consideration must be given to the position and levels of the existing feed carriers, the available hydrostatic head of the supply, the level of the outfall of the effluent and the dimensions of the contact beds to be converted. Also, the ultimate loss of actual filter area, if any, by the conversion must be considered, the initial and maintenance costs of the distributing machine, accessories, etc., together with the necessary structural alterations to the existing works and their costs.

A detailed account of actual work on such a conversion is given.

Some Notes on "The Elevator" as Used in Sewage Disposal. By E. B. Birkett. A general outline of the machine, discussing in particular the carrying chains. An elevator used for lifting the detritus out of the detritus tanks consists of a number of buckets spaced at regular intervals between two chains. These chains revolve over sprocket wheels fixed at the "head" and "boot" of the elevator. Formulae are given for the capacity of elevators.

Sewage Purification. By William E. Kelly. A very general discussion.

River Pollution. By F. H. Heald. The author claims that the local

authorities are responsible for abating the pollution of rivers. From an angler's point of view a river which supports fish life is unpolluted.

Observations and Experiences in the Design and Construction of a Sewage Purification Works. By W. H. E. Makepeace. Abstracted in THIS JOURNAL, **4**: 707 (1932).

Some Notes on the Treatment of Gas Liquor. By J. Hurley. *Ibid.*, **4**: 709 (1932).

Some Notes on Suspended Matter as it Occurs in Sewage and Tank Effluents. By A. Holroyd. The author has made a laboratory study comparing three methods for determining suspended solids, *viz.*, Gooch crucible, centrifugal, and a modified Imhoff cone method. The two former methods are described in the Ministry of Health Standard Methods. It was found that the centrifugal method gave results about 20 per cent lower than those by the Gooch crucible. In regard to these two methods Holroyd states: "The value of the Centrifuge Test lies in the fact that it records only particulate matter present in the liquor at the time of the test and removable under the gravitational field produced by the machine, but results are likely to fluctuate if the sample stands for any length of time, owing to flocculation.

"The Gooch crucible has the advantage of giving a more consistent result as it retains every thing that could possibly be considered suspended matter—and apparently—a little more besides. Its results bear little relationship to working conditions."

The author has modified the Imhoff cone method to give gravimetric results. (The method is practically identical with the method proposed by Dr. Buswell.) The sample of sewage or tank effluent is allowed to settle in the cone for two hours. At the end of this time the volume is read and the top liquor carefully decanted from the sludge. The volume of liquid remaining is noted and the whole washed into a weighed dish, dried at 100° C. and reweighed. The residue thus measured requires correcting for dissolved solids. The author found it advisable to use a constant figure for this, namely, 1000 p.p.m. This constant, of course, can and should be determined for any particular sewage.

The method accords very well with actual working conditions and an extremely close agreement was obtained between actual measured sludge production and calculations of sludge productions based on the averages of this test.

A long discussion follows the paper.

Sewage Disposal at Todmorden. By J. H. Lumb. Abstracted in THIS JOURNAL, **4**: 711 (1932).

Present Condition of Our Rivers from a Standpoint of Pollution. By E. C. Jee. *Ibid.*, **4**: 1080 (1932).

The Settlement of Activated Sludge. By W. Clifford. *Ibid.*, **4**: 906 (1932).

The Sewerage and Sewage Disposal of Lytham St. Annes. By G. W. Lawson. There are two main outfalls where storage tanks, screens and powerful pumps are installed so that the sewage may be delivered at any desired state of the tide so that it will be carried directly to the sea.

Review of the Sewage Disposal Plant (Reigate Works). By A. E. Clouds. A very general description of the destructor for the complete hygienic disposal of refuse delivered to the plant.

Buxton Sewage Disposal Works. By F. Oliver. An interesting feature of the plant is that chalybeate water, containing 6 or 7 grains per gallon of iron is added to the sewage just ahead of the coarse screens. Sewage is conveyed by gravity to the works. The dry weather flow is 1 m.g.d. The plant consists of coarse bar screen, detritus tanks, Simplex back-delivery mechanically driven screens, precipitation tanks, rough clarifying filters, and percolating filters. Sludge from the precipitation tanks is pumped to two elevated sludge tanks, from which the water is periodically decanted. From this tank, the sludge flows by gravity to a mixing tank, where milk of lime is added and the entire mixture agitated. The sludge, after liming and mixing, is then filter pressed. Average amount of lime used is 10 per cent. Approximately 20 tons of pressed sludge is produced per week.

An average analysis of the sewage for January through July, 1932, shows 4-hour oxygen absorbed value of the raw sewage as 50 p.p.m. and of the final effluent 7.3; and nitrate nitrogen in the effluent, 9.8 p.p.m.

Some Disjointed Remarks on Sewage Disposal. By J. H. Garner. The author discusses in a general way the important points in the treatment of sewage, such as measurement of flow, nature and strength of sewage, screening, detritus tanks, dosing chambers, treatment of humus sludge, and sludge digestion.

The Disposal of Activated Sludge. By Arnold Kershaw. Abstracted in THIS JOURNAL, **5**: 178 (1933).

Some Factors in the Development of the Activated Sludge Process. By F. R. O'Shaughnessy. A very brief resume of Adeney's, Stoddart's, Corbett's, Watson's, the Iddesleigh Commission's, Fowler's and Mumford's work.

Louis Pasteur: His Life and Work. By William T. Lockett. A brief resume.

Control of the Sewage Filter Fly (Psychoda). By W. D. Scouller. Abstracted in THIS JOURNAL, **5**: 185 (1933).

The Effect of Iron on Sewage Purification. By W. D. Scouller. *Ibid.*, **5**: 187 (1933).

Aeration Experiments in a Continuous Laboratory Apparatus. By W. D. Scouller and W. Watson. An ingenious apparatus was designed so as to study aeration using a continuous flow. The first series of experiments consisted of treating sewage, which contained textile and

chemical wastes, at different rates and each was settled for 1½ hours after aeration. The time of aeration in the four tests was 5, 6⅔, 10 and 20 hours. The purification based on the 4-hour oxygen absorbed test was 65.5, 67.1, 68.8 and 69.8 per cent, respectively.

In the second series, settled sewage was treated for 4, 8, 16 and 32 hours. The purification based on oxygen absorbed figures was 53, 60.9, 66.2 and 64.3 per cent, respectively. The dissolved oxygen taken up in 5 days showed that purification was practically complete in 16 hours.

Ten per cent by volume, after one hour's settlement of sludge was used in all of the experiments. The sludge was dark red in color and contained 11 per cent of iron on the dry basis. In the first series this was reduced to about 3 per cent and in the second to 2 per cent.

Activated Sludge. A New Process for Partial De-Watering and Subsequent Disposal. By H. D. Bell. Abstracted in THIS JOURNAL, **5**: 174 (1933).

The Bio-chemical, Bio-physical and Physical Principles Underlying the Self-Purification of Crude Sewage Liquors. By W. E. Adeney. Abstracted in THIS JOURNAL, **4**: 903 (1932).

The Bacterial Purification of Gasworks Liquors. The Action of the Liquors on the Bacterial Flora of Sewage. By F. C. Happold and Arthur Key. It has been common practice to purify the spent liquor resulting from the recovery of ammonia from gaswork ammonia liquor by mixing this liquor with sewage and allowing the mixture to perculate through bacteria beds. This, of course, is quite satisfactory if there is a very great volume of sewage (say 200 times) to the volume of spent liquor. Obviously this is not always the case. It was questionable as to whether the removal of phenolic substances was a true biological process and this could be shown by correlating the bacteriological findings with the efficiency of working of the beds.

A study was therefore made of the bacterial flora in sewage supplied to, and the effluent from, the bacteria beds which deal with the liquors produced at the Coventry gasworks. The author has summarized the paper as follows: "A high count in the effluent from the beds of bacteria containing an oxidase system, or a relatively large increase in the viability of such organisms when compared with the original sewage, has been found to be concurrent with good purification in the beds, and *vice versa*.

"The bacterial flora undergoes considerable modification in the beds, and also when mixed with 4 per cent of its volume of spent liquor in the laboratory. The total viable count of the treated sewage is reduced under these conditions, but the count of those bacteria which give the direct oxidase reaction and therefore catalyse the oxidation of catechol is relatively increased.

"A gram negative vibrio (strain 0 1) is the only bacterium isolated which has proved capable of breaking down monohydric phenols. It has been constantly isolated from the effluent liquors.

"Gasworks' ammonia liquor in the relatively high concentrations used exerts a markedly toxic action on all types of sewage bacteria, and the purification of this liquor by the beds is not so satisfactory. The toxicity is probably caused by the highly alkaline reaction of the liquor."

H. GLADYS SWOPE

CHLORINATION IN SEWAGE DISPOSAL

The American Public Health Association announces the publication of the Report of its Committee on Sewage Disposal of the Public Health Engineering Section, presented at the Sixty-Second Annual Meeting in Indianapolis, October 10, 1933.

The report on sewage disposal is a detailed review of the use of chlorination in sewage treatment, in its various phases. It contains a brief resume of the history of chlorination, the methods of application, the theories of chlorination, the effect of chlorination upon raw sewage and various treated sewages. Particular stress is given to a study of the removal of B.O.D. and effect of chlorinated effluents upon the streams. The use of chlorination in the control of sewage treatment operations and its effect in reduction of odors is covered, as well as its effect upon sludge digestion. Its use in connection with large scale projects to protect bathing beaches and water supplies is also noted. Numerous up-to-date references are given, with sufficient excerpts to indicate the results obtained by various authorities, and their conclusions. It should prove of interest to everyone who is interested in handling sewage and will be of value to those more particularly concerned with water supply as well.

The report contains 52 pages, is bound in paper covers, and is free to members of the Public Health Engineering Section of the American Public Health Association. The cost to others is 75 cents per copy and may be secured from the Association office at 50 West 50th Street, New York, N. Y.

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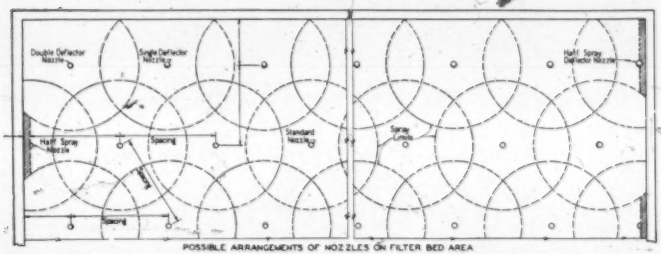

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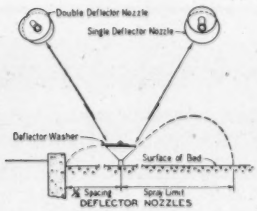

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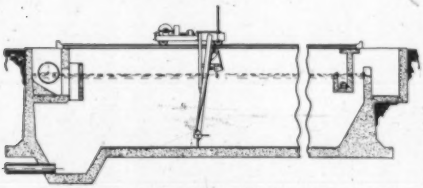

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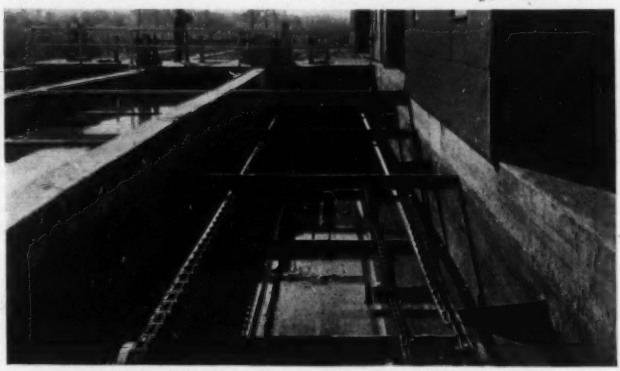

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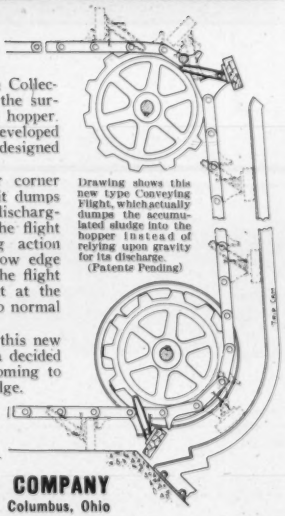

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